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Volume 1. Stationary Point and Area Sources
Fourth Edition. Supplement B

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Research Triangle Park, NC

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16. ABSTRACT

In ~~this~~ the Supplement to the Fourth Edition of AP-42, new or revised emissions data are presented for Bituminous And Subbituminous Coal Combustion; Anthracite Coal Combustion; Residential Wood Stoves; Waste Oil Combustion; Refuse Combustion; Sewage Sludge Incineration; Surface Coating; Polyester Resin Plastics Product Fabrication; Soap And Detergents; Grain Elevators And Processing Plants; Lime Manufacturing; Crushed Stone Processing; Western Surface Coal Mining; Wildfires And Prescribed Burning; Unpaved Roads; Aggregate Handling And Storage Piles; Industrial Paved Roads; Industrial Wind Erosion; and Appendix C.3, "Silt Analysis Procedures".

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Volume I: Stationary Point And Area Sources

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office Of Air And Radiation
Office Of Air Quality Planning And Standards
Research Triangle Park, North Carolina 27711

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Supplement B

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1.1 BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION

1.1.1 General[1]

Coal is a complex combination of organic matter and inorganic ash formed over eons from successive layers of fallen vegetation. Coal types are broadly classified as anthracite, bituminous, subbituminous or lignite, and classification is made by heating values and amounts of fixed carbon, volatile matter, ash, sulfur and moisture. Formulas for differentiating coals based on these properties are given in Reference 1. See Sections 1.2 and 1.7 for discussions of anthracite and lignite, respectively.

There are two major coal combustion techniques, suspension firing and grate firing. Suspension firing is the primary combustion mechanism in pulverized coal and cyclone systems. Grate firing is the primary mechanism in underfeed and overfeed stokers. Both mechanisms are employed in spreader stokers.

Pulverized coal furnaces are used primarily in utility and large industrial boilers. In these systems, the coal is pulverized in a mill to the consistency of talcum powder (i. e., at least 70 percent of the particles will pass through a 200 mesh sieve). The pulverized coal is generally entrained in primary air before being fed through the burners to the combustion chamber, where it is fired in suspension. Pulverized coal furnaces are classified as either dry or wet bottom, depending on the ash removal technique. Dry bottom furnaces fire coals with high ash fusion temperatures, and dry ash removal techniques are used. In wet bottom (slag tap) furnaces, coals with low ash fusion temperatures are used, and molten ash is drained from the bottom of the furnace. Pulverized coal furnaces are further classified by the firing position of the burners, i. e., single (front or rear) wall, horizontally opposed, vertical, tangential (corner fired), turbo or arch fired.

Cyclone furnaces burn low ash fusion temperature coal crushed to a 4 mesh size. The coal is fed tangentially, with primary air, to a horizontal cylindrical combustion chamber. In this chamber, small coal particles are burned in suspension, while the larger particles are forced against the outer wall. Because of the high temperatures developed in the relatively small furnace volume, and because of the low fusion temperature of the coal ash, much of the ash forms a liquid slag which is drained from the bottom of the furnace through a slag tap opening. Cyclone furnaces are used mostly in utility and large industrial applications.

In spreader stokers, a flipping mechanism throws the coal into the furnace and onto a moving fuel bed. Combustion occurs partly in suspension and partly on the grate. Because of significant carbon in the particulate, flyash reinjection from mechanical collectors is commonly employed to improve boiler efficiency. Ash residue in the fuel bed is deposited in a receiving pit at the end of the grate.

TABLE 1.1-1. EMISSION FACTORS FOR EXTERNAL BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION[a]

Firing Configuration	Particulate[b]		Sulfur Oxides[c]		Nitrogen Oxides[d]		Carbon Monoxide[e]		Nonmethane VOC[e,f]		Methane[e]	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Pulverized coal fired Dry bottom	5A	10A	19.5S(17.5S)	39S(35S)	10.5(7.5)[g]	21(15)[g]	0.3	0.6	0.04	0.07	0.015	0.03
Wet bottom	3.5A[h]	7A[h]	19.5S(17.5S)	39S(35S)	17	34	0.3	0.6	0.04	0.07	0.015	0.03
Cyclone furnace	1A[h]	2A[h]	19.5S(17.5S)	39S(35S)	18.5	37	0.3	0.6	0.04	0.07	0.015	0.03
Spreader stoker Uncontrolled	30[j]	60[j]	19.5S(17.5S)	39S(35S)	7	14	2.5	5	0.04	0.07	0.015	0.03
After multiple cyclone With fly ash reinjection from multiple cyclone	8.5	17	19.5S(17.5S)	39S(35S)	7	14	2.5	5	0.04	0.07	0.015	0.03
No fly ash reinjection from multiple cyclone	6	12	19.5S(17.5S)	39S(35S)	7	14	2.5	5	0.04	0.07	0.015	0.03
Overfeed stoker[k] Uncontrolled	8[m]	16[m]	19.5S(17.5S)	39S(35S)	3.25	7.5	3	6	0.04	0.07	0.015	0.03
After multiple cyclone	4.5[n]	9[n]	19.5S(17.5S)	39S(35S)	3.25	7.5	3	6	0.04	0.07	0.015	0.03
Underfeed stoker Uncontrolled	7.5[p]	15[p]	15.5S	31S	4.75	9.5	5.5	11	0.65	1.3	0.4	0.8
After multiple cyclone	5.5[n]	11[n]	15.5S	31S	4.75	9.5	5.5	11	0.65	1.3	0.4	0.8
Handfired units	7.5	15	15.5S	31S	1.5	3	45	90	5	10	4	8

[a] Factors represent uncontrolled emissions unless otherwise specified and should be applied to coal consumption as fired.

[b] Based on EPA Method 5 (front half catch) as described in Reference 12. Where particulate is expressed in terms of coal ash content, A, factor is determined by multiplying weight % ash content of coal (as fired) by the numerical value preceding the "A". For example, if coal having 8% ash is fired in a dry bottom unit, the particulate emission factor would be 5 x 8, or 40 kg/Mg (80 lb/ton). The "condensible" matter collected in back half catch of EPA Method 5 averages <5% of front half, or "filterable", catch for pulverized coal and cyclone furnaces; 10% for spreader stokers; 15% for other stokers; and 50% for handfired units (References 6, 19, 49).

[c] Expressed as SO_2, including SO_2, SO_3 and gaseous sulfates. Factors in parentheses should be used to estimate gaseous SO_x emissions for subbituminous coal. In all cases, "S" is weight % sulfur content of coal as fired. See Footnote b for example calculation. On average for bituminous coal, 97% of fuel sulfur is emitted as SO_2, and only about 0.7% of fuel sulfur is emitted as SO_3 and gaseous sulfate. An equally small percent of fuel sulfur is emitted as particulate sulfate (References 9, 13). Small quantities of sulfur are also retained in bottom ash. With subbituminous coal generally about 10% more fuel sulfur is retained in the bottom ash and particulate because of the more alkaline nature of the coal ash. Conversion to gaseous sulfate appears about the same as for bituminous coal.

[d] Expressed as NO_2. Generally, 95 - 99 volume % of nitrogen oxides present in combustion exhaust will be in the form of NO, the rest NO_2 (Reference 11). To express factors as NO, multiply by factor of 0.66. All factors represent emission at baseline operation (i.e., 60 - 110% load and no NO_x control measures, as discussed in text).

[e] Nominal values achieveable under normal operating conditions. Values one or two orders of magnitude higher can occur when combustion is not complete.

[f] Nonmethane volatile organic compounds (VOC), expressed as C_2 to C_{16} n-alkane equivalents (Reference 58). Because of limited data on NMVOC available to distinguish the effects of firing configuration, all data were averaged collectively to develop a single average for pulverized coal units, cyclones, spreaders and overfeed stokers.

[g] Parenthetic value is for tangentially fired boilers.

[h] Uncontrolled particulate emissions, when no fly ash reinjection is employed. When control device is installed, and collected fly ash is reinjected to boiler, particulate from boiler reaching control equipment can increase by up to a factor of two.

[j] Accounts for fly ash settling in an economizer, air heater or breeching upstream of control device or stack. (Particulate directly at boiler outlet typically will be twice this level.) Factor should be applied even when fly ash is reinjected to boiler from boiler, air heater or economizer dust hoppers.

[k] Includes traveling grate, vibrating grate and chain grate stokers.

[m] Accounts for fly ash settling in breeching or stack base. Particulate loadings directly at boiler outlet typically can be 50% higher.

[n] See text for discussion of apparently low multiple cyclone control efficiencies, regarding uncontrolled emissions.

[p] Accounts for fly ash settling in breeching downstream of boiler outlet.

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TABLE 1.1-2. EMISSION FACTOR RATINGS* AND REFERENCES FOR BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION

Firing Configuration	Particulate		Sulfur Oxides		Nitrogen Oxides		Carbon Monoxide		Nonmethane VOC		Methane	
	Rating	Ref.	Rating	Ref.	Rating	Ref.	Rating	Ref.	Rating	Ref.	Rating	Ref.
Pulverized coal fired												
Dry bottom	A	14-25	A	9,16-19,21, 31-37,39, 41-46,51-55	A	11,14,16-17, 21,46,56	A	16,18-19,21 47,57	A	55,58	A	58
Wet bottom	D	14,16,26	A	"	C	14,16	A	"	A	58	A	"
Cyclone furnace	D	14,19,22, 27-29	A	"	B	11	A	"	A	"	A	"
Spreader stoker												
Uncontrolled	B	17,30-35	A	"	A	11,17,31-37 39-40,46	A	17,19,31-34, 36,47,51	A	"	A	"
After multiple cyclone												
With flyash reinjection from cyclone	B	14,32,36-38	A	"	A	"	A	"	A	"	A	"
No flyash reinjection from cyclone	A	17,31-35, 39,40,59	A	"	A	"	A	"	A	"	A	"
Overfeed stoker												
Uncontrolled	B	6,17,41-43, 45-47	A	"	A	11,17,19, 41-45	B	17,41-42,45, 47,51	A	"	A	"
After multiple cyclone	B	6,41,44-45	A	"	A	"	B	"	A	"	A	"
Underfeed stoker												
Uncontrolled	B	6,19,47-48	B	19,48	B	19,47-48	B	19,47-48	A	47,58	A	47,58
After multiple cyclone	C	6	B	"	B	"	B	"	A	"	A	"
Handfired units	D	49-50	D	"	D	50	D	50	D	50,58	D	50,58

*These ratings, in the context of this Section, refer to the number of test data on which each emission factor is based. An "A" rating means the factor is based on tests at ten or more boilers, a "B" rating on six to nine test data, and a "C" rating on test data for two to five boilers. A "D" rating indicates the factor is based on only a single datum or extrapolated from a secondary reference. These ratings are not a measure of the scatter in the underlying test data. However, a higher rating will generally increase confidence that a given factor will better approximate the average emissions for a particular boiler category.

In overfeed stokers, coal is fed onto a traveling or vibrating grate, and it burns on the fuel bed as it progresses through the furnace. Ash particles fall into an ash pit at the rear of the stoker. The term "overfeed" applies because the coal is fed onto the moving grate under an adjustable gate. Conversely, in "underfeed" stokers, coal is fed into the firing zone from underneath by mechanical rams or screw conveyers. The coal moves in a channel, known as a retort, from which it is forced upward, spilling over the top of each side to form and to feed the fuel bed. Combustion is completed by the time the bed reaches the side dump grates from which the ash is discharged to shallow pits. Underfeed stokers include single retort units and multiple retort units, the latter having several retorts side by side.

1.1.2 Emissions And Controls

The major pollutants of concern from external coal combustion are particulate, sulfur oxides and nitrogen oxides. Some unburnt combustibles, including numerous organic compounds and carbon monoxide, are generally emitted even under proper boiler operating conditions.

Particulate[2-4] - Particulate composition and emission levels are a complex function of firing configuration, boiler operation and coal properties. In pulverized coal systems, combustion is almost complete, and thus particulate largely comprises inorganic ash residue. In wet bottom pulverized coal units and cyclones, the quantity of ash leaving the boiler is less than in dry bottom units, since some of the ash liquifies, collects on the furnace walls, and drains from the furnace bottom as molten slag. To increase the fraction of ash drawn off as wet slag, and thus to reduce the flyash disposal problem, flyash may be reinjected from collection equipment into slag tap systems. Dry bottom unit ash may also be reinjected into wet bottom boilers for the same purpose.

Because a mixture of fine and coarse coal particles is fired in spreader stokers, significant unburnt carbon can be present in the particulate. To improve boiler efficiency, flyash from collection devices (typically multiple cyclones) is sometimes reinjected into spreader stoker furnaces. This practice can dramatically increase the particulate loading at the boiler outlet and, to a lesser extent, at the mechanical collector outlet. Flyash can also be reinjected from the boiler, air heater and economizer dust hoppers. Flyash reinjection from these hoppers does not increase particulate loadings nearly so much as from multiple cyclones.[5]

Uncontrolled overfeed and underfeed stokers emit considerably less particulate than do pulverized coal units and spreader stokers, since combustion takes place in a relatively quiescent fuel bed. Flyash reinjection is not practiced in these kinds of stokers.

Other variables than firing configuration and flyash reinjection can affect emissions from stokers. Particulate loadings will often increase as load increases (especially as full load is approached) and with sudden load changes. Similarly, particulate can increase as the ash and fines contents increase. ("Fines", in this context, are coal particles smaller than about 1.6 millimeters, or one sixteenth inch, in diameter.) Conversely, particulate can be reduced significantly when overfire air pressures are increased.[5]

The primary kinds of particulate control devices used for coal combustion include multiple cyclones, electrostatic precipitators, fabric filters (baghouses) and scrubbers. Some measure of control will even result from ash settling in boiler/air heater/economizer dust hoppers, large breeches and chimney bases. To the extent possible from the existing data base, the effects of such settling are reflected in the emission factors in Table 1.1-1.

Electrostatic precipitators (ESP) are the most common high efficiency control device used on pulverized coal and cyclone units, and they are being used increasingly on stokers. Generally, ESP collection efficiencies are a function of collection plate area per volumetric flow rate of flue gas through the device. Particulate control efficiencies of 99.9 weight percent are obtainable with ESPs. Fabric filters have recently seen increased use in both utility and industrial applications, generally effecting about 99.8 percent efficiency. An advantage of fabric filters is that they are unaffected by high flyash resistivities associated with low sulfur coals. ESPs located after air preheaters (i. e., cold side precipitators) may operate at significantly reduced efficiencies when low sulfur coal is fired. Scrubbers are also used to control particulate, although their primary use is to control sulfur oxides. One drawback of scrubbers is the high energy requirement to achieve control efficiencies comparable to those of ESPs and baghouses.[2]

Mechanical collectors, generally multiple cyclones, are the primary means of control on many stokers and are sometimes installed upsteam of high efficiency control devices in order to reduce the ash collection burden. Depending on application and design, multiple cyclone efficiencies can vary tremendously. Where cyclone design flow rates are not attained (which is common with underfeed and overfeed stokers), these devices may be only marginally effective and may prove little better in reducing particulate than large breeching. Conversely, well designed multiple cyclones, operating at the required flow rates, can achieve collection efficiencies on spreader stokers and overfeed stokers of 90 to 95 percent. Even higher collection efficiencies are obtainable on spreader stokers with reinjected flyash, because of the larger particle sizes and increased particulate loading reaching the controls.[5-6]

Sulfur Oxides[7-9] - Gaseous sulfur oxides from external coal combustion are largely sulfur dioxide (SO_2) and much less quantity of sulfur trioxide (SO_3) and gaseous sulfates. These compounds form as the organic and pyritic sulfur in the coal is oxidized during the combustion process. On average, 98 percent of the sulfur present in bituminous coal will be emitted as gaseous sulfur oxides, whereas somewhat less will be emitted when subbituminous coal is fired. The more alkaline nature of the ash in some subbituminous coal causes some of the sulfur to react to form various sulfate salts that are retained in the boiler or in the flyash. Generally, boiler size, firing configuration and boiler operations have little effect on the percent conversion of fuel sulfur to sulfur oxides.

Several techniques are used to reduce sulfur oxides from coal combustion. One way is to switch to lower sulfur coals, since sulfur oxide emissions are proportional to the sulfur content of the coal. This alternative may not be possible where lower sulfur coal is not readily available or where a different grade of coal can not be satisfactorily fired. In some cases, various cleaning processes may be employed to reduce the fuel sulfur content. Physical coal cleaning removes mineral sulfur such as pyrite but is not effective in removing organic sulfur. Chemical cleaning and solvent refining processes are being developed to remove organic sulfur.

Many flue gas desulfurization techniques can remove sulfur oxides formed during combustion. Flue gases can be treated through wet, semidry or dry desulfurization processes of either the throwaway type, in which all waste streams are discarded, or the recovery (regenerable) type, in which the SO_x absorbent is regenerated and reused. To date, wet systems are the most commonly applied. Wet systems generally use alkali slurries as the SO_x absorbent medium and can be designed to remove well in excess of 90 percent of the incoming SO_x. Particulate reduction of up to 99 percent is also possible with wet scrubbers, but flyash is often collected by upsteam ESPs or baghouses, to avoid erosion of the desulfurization equipment and possible interference with the process reactions.[7] Also, the volume of scrubber sludge is reduced with separate flyash removal, and contamination of the reagents and byproducts is prevented. References 7 and 8 give more details on scrubbing and other SO_x removal techniques.

Nitrogen Oxides [10-11] - Nitrogen oxides (NO_x) emissions from coal combustion are primarily nitrogen oxide (NO). Only a few volume percent are nitrogen dioxide (NO_2). NO results from thermal fixation of atmospheric nitrogen in the combustion flame and from oxidation of nitrogen bound in the coal. Typically, only 20 to 60 percent of the fuel nitrogen is converted to nitrogen oxides. Bituminous and subbituminous coals usually contain from 0.5 to 2 weight percent nitrogen, present mainly in aromatic ring structures. Fuel nitrogen can account for up to 80 percent of total NO_x from coal combustion.

A number of combustion modifications can be made to reduce NO_x emissions from boilers. Low excess air (LEA) firing is the most widespread control modification, because it can be practiced in both old and new units and in all sizes of boilers. LEA firing is easy to implement and has the added advantage of increasing fuel use efficiency. LEA firing is generally effective only above 20 percent excess air for pulverized coal units and above 30 percent excess air for stokers. Below these levels, the NO_x reduction from decreased O_2 availability is offset by increased NO_x because of increased flame temperature. Another NO_x reduction technique is simply to switch to a coal having a lower nitrogen content, although many boilers may not properly fire coals of different properties.

Off-stoichiometric (staged) combustion is also an effective means of controlling NO_x from coal fired equipment. This can be achieved by using overfire air or low NO_x burners designed to stage combustion in the flame zone. Other NO_x reduction techniques include flue gas recirculation, load reduction, and steam or water injection. However, these techniques are not very effective for use on coal fired equipment because of the fuel nitrogen effect. Ammonia injection is another technique which can be used, but it is costly. The net reduction of NO_x from any of these techniques or combinations thereof varies considerably with boiler type, coal properties and existing operating practices. Typical reductions will range from 10 to 60 percent. References 10 and 60 should be consulted for a detailed discussion of each of these NO_x reduction techniques. To date, flue gas treatment is not used to reduce nitrogen oxide emissions because of its higher cost.

Volatile Organic Compounds And Carbon Monoxide - Volatile organic compounds (VOC) and carbon monoxide (CO) are unburnt gaseous combustibles which generally are emitted in quite small amounts. However, during startups, temporary upsets or other conditions preventing complete combustion, unburnt combustible emissions may increase dramatically. VOC and CO emissions per unit of fuel fired are normally lower from pulverized coal or cyclone furnaces than from smaller stokers and handfired units where operating conditions are not so well controlled. Measures used for NO_x control can increase CO emissions, so to reduce the risk of explosion, such measures are applied only to the point at which CO in the flue gas reaches a maximum of about 200 parts per million. Other than maintaining proper combustion conditions, control measures are not applied to control VOC and CO.

Emission Factors And References - Emission factors for several pollutants are presented in Table 1.1-1, and factor ratings and references are presented in Table 1.1-2. The factors for uncontrolled underfeed stokers and hand fired units also may be applied to hot air furnaces. Tables 1.1-3 through 1.1-8 present cumulative size distribution data and size specific emission factors for particulate emissions from the combustion sources discussed above. Uncontrolled and controlled size specific emission factors are presented in Figures 1.1-1 through 1.1-6.

TABLE 1.1-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR DRY BOTTOM BOILERS BURNING PULVERIZED BITUMINOUS COAL[a]

EMISSION FACTOR RATING: C (uncontrolled)
D (scrubber and ESP controlled
E (multiple cyclone and baghouse)

Particle size[b] (µm)	Cumulative mass % ≤ stated size					Cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]				
	Uncontrolled	Controlled				Uncontrolled	Controlled[d]			
		Multiple cyclone	Scrubber	ESP	Baghouse		Multiple cyclone	Scrubber	ESP	Baghouse
15	32	54	81	79	97	1.6A (3.2A)	0.54A (1.08A)	0.24A (0.48A)	0.032A (0.06A)	0.010A (0.02A)
10	23	29	71	67	92	1.15A (2.3A)	0.29A (0.58A)	0.21A (0.42A)	0.027A (0.05A)	0.009A (0.02A)
6	17	14	62	50	77	0.85A (1.7A)	0.14A (0.28A)	0.19A (0.38A)	0.020A (0.04A)	0.008A (0.02A)
2.5	6	3	51	29	53	0.30A (0.6A)	0.03A (0.06A)	0.15A (0.3A)	0.012A (0.02A)	0.005A (0.01A)
1.25	2	1	35	17	31	0.10A (0.2A)	0.01A (0.02A)	0.11A (0.22A)	0.007A (0.01A)	0.003A (0.006A)
1.00	2	1	31	14	25	0.10A (0.2A)	0.01A (0.02A)	0.09A (0.18A)	0.006A (0.01A)	0.003A (0.006A)
0.625	1	1	20	12	14	0.05A (0.10)	0.01A (0.02A)	0.06A (0.12A)	0.005A (0.01A)	0.001A (0.002A)
TOTAL	100	100	100	100	100	5A (10A)	1A (2A)	0.3A (0.6A)	0.04A (0.08A)	0.01A (0.02A)

[a] Reference 61. ESP = electrostatic precipitator.
[b] Expressed as aerodynamic equivalent diameter.
[c] A = coal ash weight %, as fired.
[d] Estimated control efficiency for multiple cyclone, 80%; scrubber, 94%; ESP, 99.2%; baghouse, 99.8%.

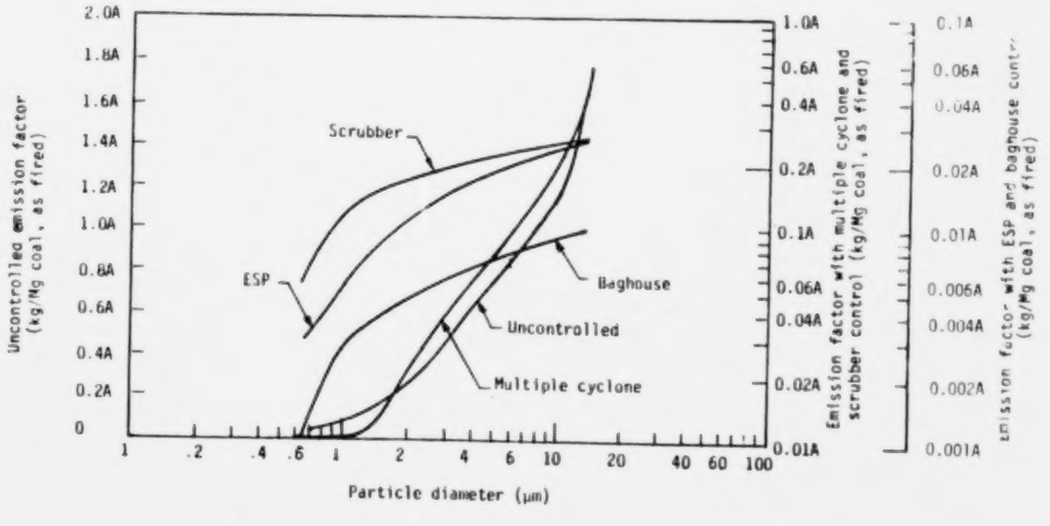

Figure 1.1-1. Cumulative size specific emission factors for dry bottom boilers burning pulverized bituminous coal.

TABLE 1.1-4. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR WET BOTTOM BOILERS BURNING PULVERIZED BITUMINOUS COAL[a]

EMISSION FACTOR RATING: E

Particle size[b] (μm)	Cumulative mass % ≤ stated size			Cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]		
	Uncontrolled	Controlled		Uncontrolled	Controlled[d]	
		Multiple cyclone	ESP		Multiple cyclone	ESP
15	40	99	83	1.4A (2.8A)	0.69A (1.38A)	0.023A (0.046A)
10	37	93	75	1.30A (2.6A)	0.65A (1.3A)	0.021A (0.042A)
6	33	84	63	1.16A (2.32A)	0.59A (1.18A)	0.018A (0.036A)
2.5	21	61	40	0.74A (1.48A)	0.43A (0.86A)	0.011A (0.022A)
1.25	6	31	17	0.21A (0.42A)	0.22A (0.44A)	0.005A (0.01A)
1.00	4	19	8	0.14A (0.28A)	0.13A (0.26A)	0.002A (0.004A)
0.625	2	e	e	0.07A (0.14A)	e	e
TOTAL	100	100	100	3.5A (7.0A)	0.7A (1.4A)	0.028A (0.056A)

[a] Reference 61. ESP = electrostatic precipitator.
[b] Expressed as aerodynamic equivalent diameter.
[c] A = coal ash weight %, as fired.
[d] Estimated control efficiency for multiple cyclone, 80%; ESP, 99.2%.
[e] Insufficient data.

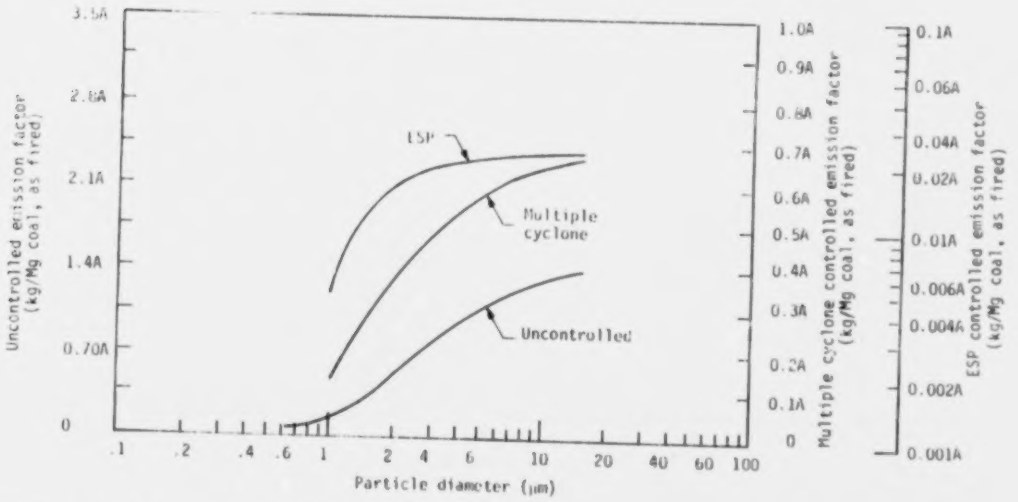

Figure 1.1-2. Cumulative size specific emission factors for wet bottom boilers burning pulverized bituminous coal

TABLE 1.1-5. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR CYCLONE FURNACES BURNING BITUMINOUS COAL[a]

EMISSION FACTOR RATING: E

Particle size[b] (μm)	Cumulative mass % ≤ stated size			Cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]		
	Uncontrolled	Controlled		Uncontrolled	Controlled[e]	
		Scrubber	ESP		Scrubber	ESP
15	33	95	90	0.33A (0.66A)	0.057A (0.114A)	0.0064A (0.013A)
10	13	94	68	0.13A (0.26A)	0.056A (0.112A)	0.0054A (0.011A)
6	8	93	56	0.08A (0.16A)	0.056A (0.112A)	0.0045A (0.009A)
2.5	0	92	36	0 (0)	0.055A (0.11A)	0.0029A (0.006A)
1.25	0	85	22	0 (0)	0.051A (0.10A)	0.0018A (0.004A)
1.00	0	82	17	0 (0)	0.049A (0.10A)	0.0014A (0.003A)
0.625	0	d	d	0 (0)	d	d
TOTAL	100	100	100	1A (2A)	0.06A (0.12A)	0.008A (0.016A)

[a] Reference 61. ESP = electrostatic precipitator.
[b] Expressed as aerodynamic equivalent diameter.
[c] A = coal ash weight %, as fired.
[d] Insufficient data.
[e] Estimated control efficiency for scrubber, 94%; ESP, 99.2%.

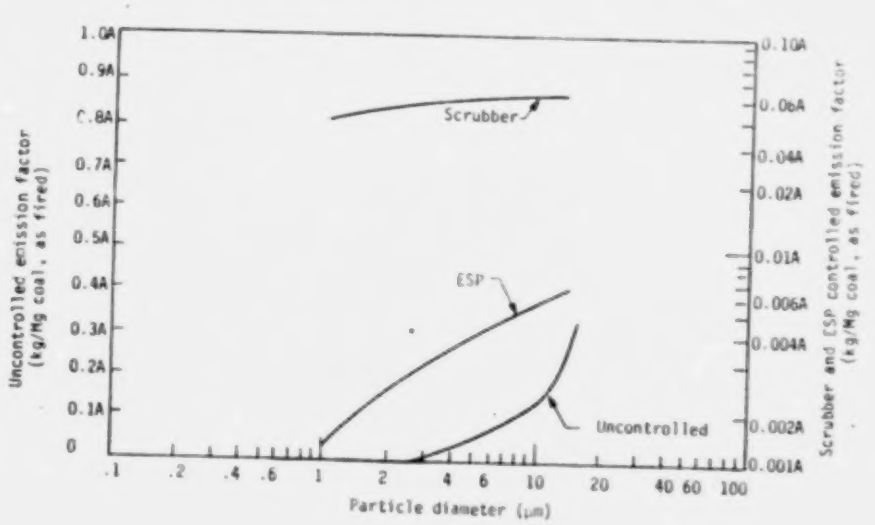

Figure 1.1-3. Cumulative size specific emission factors for cyclone furnaces burning bituminous coal

TABLE 1.1-6. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR SPREADER STOKERS BURNING BITUMINOUS COAL[a]

EMISSION FACTOR RATING: C (uncontrolled and controlled for multiple cyclone without flyash reinjection, and with baghouse)
E (multiple cyclone controlled with flyash reinjection, and ESP controlled)

Particle size[b] (μm)	Cumulative mass % ≤ stated size					Cumulative emission factor [kg/Mg (lb/ton) coal, as fired]				
	Uncontrolled	Controlled				Uncontrolled	Controlled			
		Multiple cyclone[c]	Multiple cyclone[d]	ESP	Baghouse		Multiple cyclone[c]	Multiple cyclone[d]	ESP	Baghouse
15	28	86	74	97	72	8.4 (16.8)	7.3 (14.6)	4.4 (8.8)	0.23 (0.46)	0.043 (0.086)
10	20	73	65	90	60	6.0 (12.0)	6.2 (12.4)	3.9 (7.8)	0.22 (0.44)	0.036 (0.072)
6	14	51	52	82	46	4.2 (8.4)	4.3 (8.6)	3.1 (6.2)	0.20 (0.40)	0.028 (0.056)
2.5	7	8	27	61	26	2.1 (4.2)	0.7 (1.4)	1.6 (3.2)	0.15 (0.30)	0.016 (0.032)
1.25	5	2	16	46	18	1.5 (3.0)	0.2 (0.4)	1.0 (2.0)	0.11 (0.22)	0.011 (0.022)
1.00	5	2	14	41	15	1.5 (3.0)	0.2 (0.4)	0.8 (1.6)	0.10 (0.20)	0.009 (0.018)
0.625	4	1	9	[e]	7	1.2 (2.4)	0.1 (0.2)	0.5 (1.0)	[e]	0.004 (0.008)
TOTAL	100	100	100	100	100	30.0 (60.0)	8.5 (17.0)	6.0 (12.0)	0.24[f] (0.48)	0.06[f] (0.12)

[a] Reference 61. ESP = electrostatic precipitator.
[b] Expressed as aerodynamic equivalent diameter.
[c] With flyash reinjection.
[d] Without flyash reinjection.
[e] Insufficient data.
[f] Estimated control efficiency for ESP, 99.2%; baghouse, 99.8%.

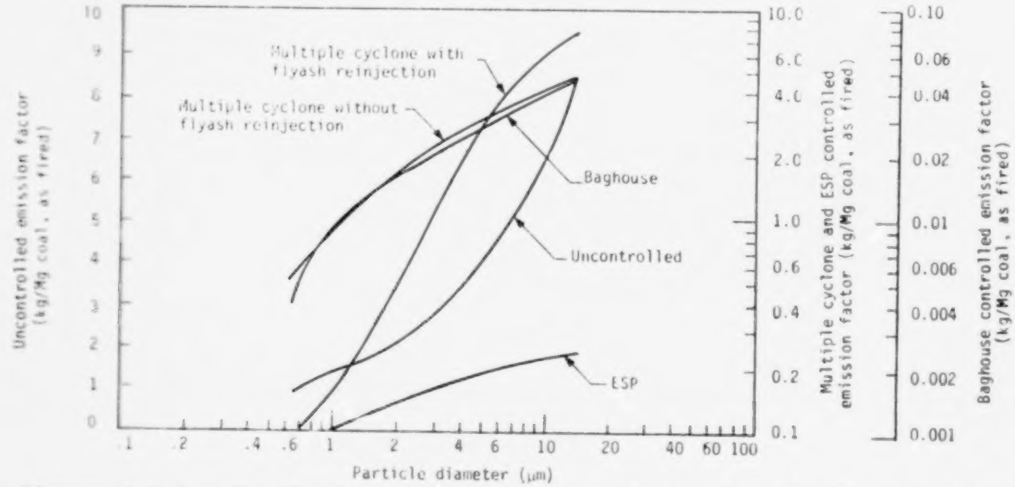

Figure 1.1-4. Cumulative size specific emission factors for spreader stokers burning bituminous coal

TABLE 1.1-7. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR OVERFEED STOKERS BURNING BITUMINOUS COAL[a]

EMISSION FACTOR RATING: C (uncontrolled)
E (multiple cyclone controlled)

Particle size[b] (μm)	Cumulative mass % ≤ stated size		Cumulative emission factor [kg/Mg (lb/ton) coal, as fired]	
	Uncontrolled	Multiple cyclone controlled	Uncontrolled	Multiple cyclone controlled[d]
15	49	60	3.9 (7.8)	2.7 (5.4)
10	37	55	3.0 (6.0)	2.5 (5.0)
6	24	49	1.9 (3.8)	2.2 (4.4)
2.5	14	43	1.1 (2.2)	1.9 (3.8)
1.25	13	39	1.0 (2.0)	1.8 (3.6)
1.00	12	39	1.0 (2.0)	1.8 (3.6)
0.625	c	16	c	0.7 (1.4)
TOTAL	100	100	8.0 (16.0)	4.5 (9.0)

[a] Reference 61.

[b] Expressed as aerodynamic equivalent diameter.

[c] Insufficient data.

[d] Estimated control efficiency for multiple cyclone, 80%.

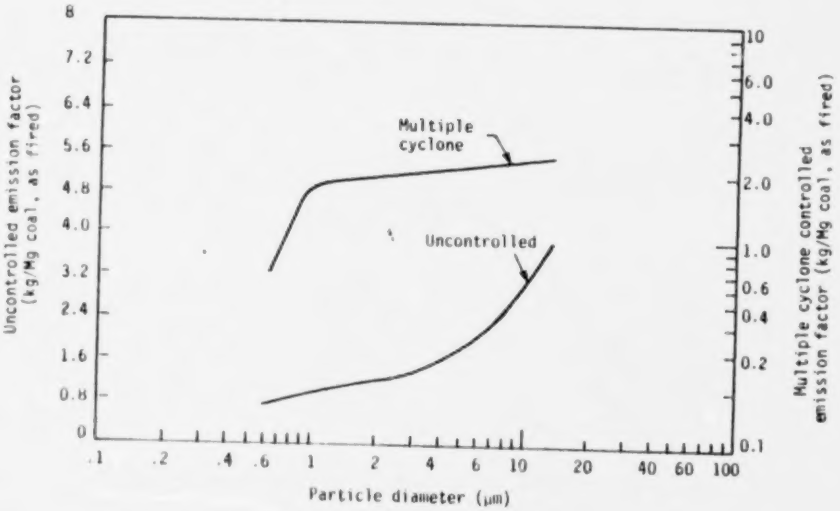

Figure 1.1-5. Cumulative size specific emission factors for overfeed stokers burning bituminous coal

TABLE 1.1-8. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR UNDERFEED STOKERS BURNING BITUMINOUS COAL[a]

EMISSION FACTOR RATING: C

Particle size[b] (μm)	Cumulative mass % ≤ stated size	Uncontrolled cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]
15	50	3.8 (7.6)
10	41	3.1 (6.2)
6	32	2.4 (4.8)
2.5	25	1.9 (3.8)
1.25	22	1.7 (3.4)
1.00	21	1.6 (3.2)
0.625	18	1.4 (2.7)
TOTAL	100	7.5 (15.0)

[a] Reference 61.

[b] Expressed as aerodynamic equivalent diameter.

[c] May also be used for uncontrolled hand fired units.

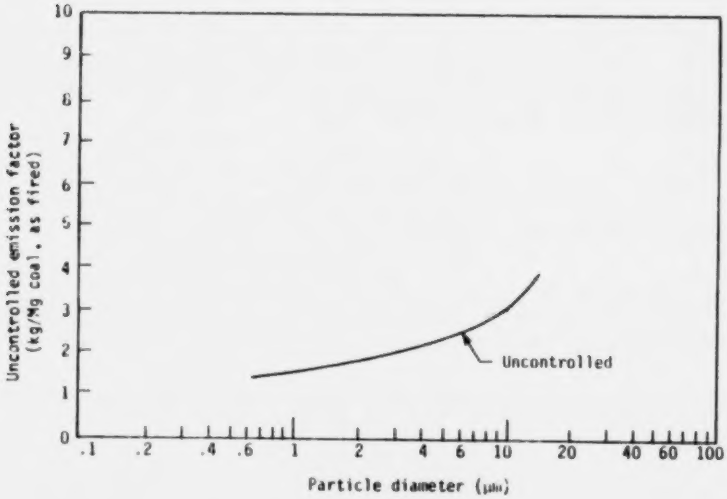

Figure 1.1-6. Cumulative size specific emission factors for underfeed stokers burning bituminous coal.

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1.2 ANTHRACITE COAL COMBUSTION

1.2.1 General[1-2]

Anthracite coal is a high rank coal with more fixed carbon and less volatile matter than either bituminous coal or lignite, and it has higher ignition and ash fusion temperatures. Because of its low volatile matter content and slight clinkering, anthracite is most commonly fired in medium sized traveling grate stokers and small hand fired units. Some anthracite (occasionally with petroleum coke) is used in pulverized coal fired boilers. It is also blended with bituminous coal. None is fired in spreader stokers. For its low sulfur content (typically less than 0.8 weight percent) and minimal smoking tendencies, anthracite is considered a desirable fuel where readily available.

In the United States, all anthracite is mined in northeastern Pennsylvania and is consumed mostly in Pennsylvania and several surrounding states. The largest use of anthracite is for space heating. Lesser amounts are employed for steam/electric production; coke manufacturing, sintering and pelletizing; and other industrial uses. Anthracite currently is only a small fraction of the total quantity of coal combusted in the United States.

1.2.2 Emissions And Controls[2-14]

Particulate emissions from anthracite combustion are a function of furnace firing configuration, firing practices (boiler load, quantity and location of underfire air, sootblowing, flyash reinjection, etc.), and the ash content of the coal. Pulverized coal fired boilers emit the highest quantity of particulate per unit of fuel because they fire the anthracite in suspension, which results in a high percentage of ash carryover into exhaust gases. Pulverized anthracite fired boilers operate in the dry tap or dry bottom mode, because of anthracite's characteristically high ash fusion temperature. Traveling grate stokers and hand fired units produce much less particulate per unit of fuel fired, because combustion takes place in a quiescent fuel bed without significant ash carryover into the exhaust gases. In general, particulate emissions from traveling grate stokers will increase during sootblowing and flyash reinjection and with higher fuel bed underfeed air from forced draft fans. Smoking is rarely a problem, because of anthracite's low volatile matter content.

Limited data are available on the emission of gaseous pollutants from anthracite combustion. It is assumed from bituminous coal combustion data that a large fraction of the fuel sulfur is emitted as sulfur oxides. Also, because combustion equipment, excess air rates, combustion temperatures, etc., are similar between anthracite and bituminous coal combustion, nitrogen oxide and carbon monoxide emissions are assumed to be similar, too. Volatile organic compound (VOC) emissions, however, are expected to be considerably lower, since the volatile matter content of anthracite is significantly less than that of bituminous coal.

TABLE 1.2-1. UNCONTROLLED EMISSION FACTORS FOR ANTHRACITE COMBUSTION[a]

Boiler type	Particulate[b]		Sulfur oxides[c]		Nitrogen oxides[d]		Carbon monoxide[e]		Volatile organics	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	Nonmethane	Methane
Pulverized coal fired	f	f	19.5S	39S	9	18	f	f	f	f
Traveling grate stoker	4.6[g]	9.1[g]	19.5S	39S	5	10	0.3	0.6	f	f
Hand fed units	5[h]	10[h]	19.5S	39S	1.5	3	f	f	f	f

[a] Factors are for uncontrolled emissions and should be applied to coal consumption as fired.

[b] Based on EPA Method 5 (front half catch).

[c] Assumes, as with bituminous coal combustion, most fuel sulfur is emitted as SO_x. Limited data in Reference 5 verify this for pulverized anthracite fired boilers. Emissions are mostly SO_2, with 1 - 3% SO_3. S indicates that weight % sulfur should be multiplied by the value given.

[d] For pulverized anthracite fired boilers and hand fed units, assumed to be similar to bituminous coal combustion. For traveling grate stokers, see References 8, 11.

[e] May increase by several orders of magnitude with boilers not properly operated or maintained. For traveling grate stokers, based on limited information in Reference 8. For pulverized coal fired boilers, substantiated by additional data in Reference 14.

[f] Factors in Table 1.1-1 may be used, based on similarity of anthracite and bituminous coal.

[g] References 12-13, 15-18. Accounts for limited fallout that may occur in fallout chambers and stack breeching. Factors for individual boilers may be 2.5 - 25 kg/Mg (5 - 50 lb/ton), highest during soot blowing.

[h] Reference 2.

Controls on anthracite emissions mainly have been applied to particulate matter. The most efficient particulate controls, fabric filters, scrubbers and electrostatic precipitators, have been installed on large pulverized anthracite fired boilers. Fabric filters and venturi scrubbers can effect collection efficiencies exceeding 99 percent. Electrostatic precipitators typically are only 90 to 97 percent efficient, because of the characteristic high resistivity of low sulfur anthracite fly ash. It is reported that higher efficiencies can be achieved using larger precipitators and flue gas conditioning. Mechanical collectors are frequently employed upstream from these devices for large particle removal.

Traveling grate stokers are often uncontrolled. Indeed, particulate control has often been considered unnecessary, because of anthracite's low smoking tendencies and of the fact that a significant fraction of large size flyash from stokers is readily collected in flyash hoppers as well as in the breeching and base of the stack. Cyclone collectors have been employed on traveling grate stokers, and limited information suggests these devices may be up to 75 percent efficient on particulate. Flyash reinjection, frequently used in traveling grate stokers to enhance fuel use efficiency, tends to increase particulate emissions per unit of fuel combusted.

Emission factors for pollutants from anthracite coal combustion are given in Table 1.2-1, and factor ratings in Table 1.2-2. Cumulative size distribution data and size specific emission factors and ratings for particulate emissions are in Tables 1.2-3 and 1.2-4. Uncontrolled and controlled size specific emission factors are presented in Figures 1.2-1 and 1.2-2. Size distribution data for bituminous coal combustion may be used for uncontrolled emissions from pulverized anthracite fired furnaces, and data for anthracite fired traveling grate stokers may be used for hand fired units.

TABLE 1.2-2. ANTHRACITE COAL EMISSION FACTOR RATINGS

Furnace type	Particulate	Sulfur oxides	Nitrogen oxides	Carbon monoxide	Volatile organics	
					Nonmethane	Methane
Pulverized coal	B	B	B	B	C	C
Traveling grate stoker	B	B	B	B	C	C
Hand fired units	B	B	B	B	D	D

TABLE 1.2-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR DRY BOTTOM BOILERS BURNING PULVERIZED ANTHRACITE COAL[a]

EMISSION FACTOR RATING: D

Particle size[b] (µm)	Cumulative mass % ≤ stated size			Cumulative emission factor[c] [kg/Mg (lb/ton) bark, as fired]		
	Uncontrolled	Controlled		Uncontrolled	Controlled[d]	
		Multiple cyclone	Baghouse		Multiple cyclone	Baghouse
15	32	63	79	1.6A (3.2A)	0.63A (1.26A)	0.0079A (0.016A)
10	23	55	67	1.2A (2.3A)	0.55A (1.10A)	0.0067A (0.013A)
6	17	46	51	0.9A (1.7A)	0.46A (0.92A)	0.0051A (0.010A)
2.5	6	24	32	0.3A (0.6A)	0.24A (0.48A)	0.0032A (0.006A)
1.25	2	13	21	0.1A (0.2A)	0.13A (0.26A)	0.0021A (0.004A)
1.00	2	10	18	0.1A (0.2A)	0.10A (0.20A)	0.0018A (0.004A)
0.625	1	7		0.05A (0.1A)	0.07A (0.14A)	e
TOTAL	100	100	100	5A (10A)	1A (2A)	0.01A (0.02A)

[a] Reference 19.
[b] Expressed as aerodynamic equivalent diameter.
[c] A = coal ash weight, as fired.
[d] Estimated control efficiency for multiple cyclone, 80%; baghouse, 99.8%.
[e] Insufficient data.

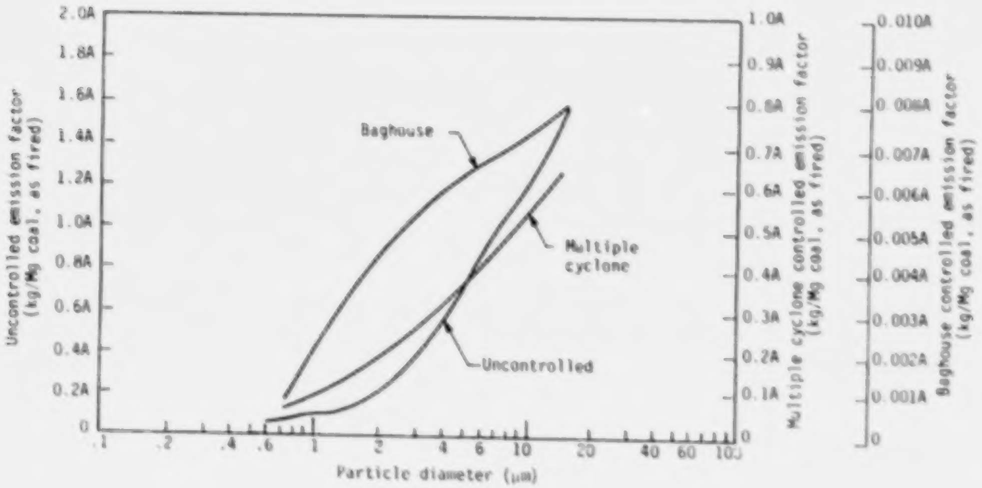

Figure 1.2-1. Cumulative size specific emission factors for dry bottom boilers burning pulverized anthracite coal.

TABLE 1.2-4. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR TRAVELING GRATE STOKERS BURNING ANTHRACITE COAL[a]

EMISSION FACTOR RATING: E

Particle size[b] (um)	Cumulative mass % ≤ stated size	Cumulative emission factor [kg/Mg (lb/ton) coal, as fired]
	Uncontrolled[c]	Uncontrolled
15	64	2.9 (5.8)
10	52	2.4 (4.8)
6	42	1.9 (3.8)
2.5	27	1.2 (2.4)
1.25	24	1.1 (2.2)
1.00	23	1.1 (2.2)
0.625	d	d
TOTAL	100	4.6 (9.2)

[a] Reference 19.
[b] Expressed as aerodynamic equivalent diameter.
[c] May also be used for uncontrolled hand fired units.
[d] Insufficient data.

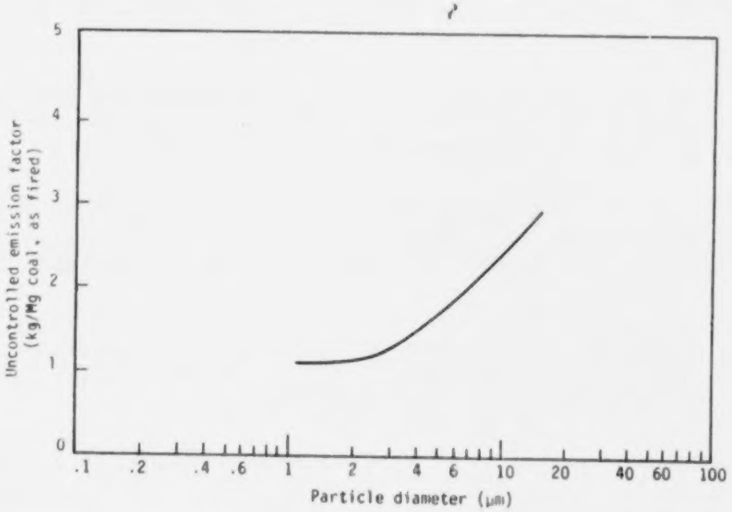

Figure 1.2-2. Cumulative size specific emission factors for traveling grate stokers burning anthracite coal.

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1.10 RESIDENTIAL WOOD STOVES

1.10.1 General[1-2]

Wood stoves are commonly used as space heaters to supplement conventional heating systems in residences. They are increasingly found as the primary source of heat, as well.

Because of differences in both the magnitude and the composition of emissions from wood stoves, four different categories of stoves should be considered when estimating emissions:

- the conventional noncatalytic wood stove
- the noncatalytic low emitting wood stove
- the pellet fired noncatalytic wood stove
- the catalytic wood stove

Among these categories, there are many variations in wood stove design and operation characteristics.

The conventional stove category comprises all stoves without catalytic combustors and are not included in the other noncatalytic categories. Stoves of many different airflow designs, such as updraft, downdraft, crossdraft, and S-flow, may be in this category.

"Noncatalytic low emitting" wood stoves are those having no catalyst and meeting EPA certification standards.

Pellet fired stoves are fueled with pellets of sawdust, wood products, and other biomass materials pressed into manageable shape and size. These stoves have a specially designed or modified grate to accommodate this type of fuel.

Catalytic stoves are equipped with a ceramic or metal honeycomb material, called a combustor or converter, that is coated with a noble metal such as platinum or palladium. The catalyst material reduces the ignition temperature of the unburned hydrocarbons and carbon monoxide in the exhaust gases, thus augmenting their ignition and combustion at normal stove operating temperatures. As these components of the gases burn, the temperature inside the catalyst increases to a point where the ignition of the gases is essentially self sustaining.

1.10.2 Emissions[3-13]

The combustion and pyrolysis of wood in wood stoves produce atmospheric emissions of particulate, carbon monoxide, nitrogen oxides, organic compounds, mineral residues, and to a lesser extent, sulfur oxides. The quantities and types of emissions are highly variable and depend on a number of factors, including the stages of the combustion cycle. During inital stages of burning, after a new wood charge is introduced, emissions increase dramatically, primarily of volatile organic compounds (VOC). After the initial period of high burn rate, there is a charcoal stage of the burn cycle, characterized by a slower burn rate and decreased emission rates. Emission rates during this stage are cyclical, characterized by relatively long periods of low emissions with shorter episodes of emission spikes.

Particulate emissions are defined in this document as the total catch measured by the EPA Method 5H (Oregon Method 7) sampling train. A small portion of wood stove particulate emissions includes "solid" particles of elemental carbon and wood. The vast majority of the particulate emissions is condensed organic products of incomplete combustion equal to or less than 10 micrometers in aerodynamic diameter (PM_{10}).

Although reported particle size data are scarce, one reference states that 95 percent of the particles in the emissions from a wood stove were less than 0.4 micrometers in size.[3]

Sulfur oxides are formed by oxidation of sulfur in the wood. Nitrogen oxides are formed by oxidation of fuel and atmospheric nitrogen. Mineral constituents, such as potassium and sodium compounds, are also released from the wood matrix during combustion. The high levels of organic compound and carbon monoxide emissions result from incomplete combustion of the wood.

Organic constituents of wood smoke vary considerably in both type and volatility. These constituents include simple hydrocarbons (C_1-C_7), which exist as gases or which volatilize at ambient conditions, and complex low volatility substances which condense at ambient conditions. These low volatility condensable materials are generally considered to have boiling points below 300°C (572°F).

Polycyclic organic matter (POM) is an important component of the condensable fraction of wood smoke. POM contains a wide range of compounds, including organic compounds formed by the combination of free radical species in the flame zone through incomplete combustion. This group contains some potentially carcinogenic compounds, such as benzo(a)pyrene.

Emission factors and their ratings for wood combustion in residential wood stoves are presented in Table 1.10-1.

As mentioned, particulate emissions are defined as the total emissions collected by EPA Method 5H (Oregon Method 7). This method employs a heated filter followed by three impingers, an unheated filter, and a final impinger. Emissions data used to develop the factors in Table 1.10-1 are from a data base developed during EPA certification tests and from data collected during field testing programs. See Reference 1 for detailed discussions of EPA Methods 5H and 28.

Note that the data shown on Table 1.10-1 have been derived primarily from laboratory tests. Review of some emission tests of woodstoves in actual use indicates that laboratory tests may underestimate actual emissions significantly. Evaluation of field test results is proceeding, with completion scheduled for October 1988.

TABLE 1.10-1. EMISSION FACTORS FOR COMBUSTION IN RESIDENTIAL WOOD STOVES[a]

Stove type	Particulate[b,c] ≤ 10um	Carbon monoxide[b]	Nitrogen oxides[b]	Sulfur oxides[d]	Volatile organics[e]	
					Methane	Nonmethane
Catalytic						
g/hr	-	57	1.5	0.2	24	14
g/kg (lb/ton)	-	39 (78)	1.0 (2.0)	0.2 (0.4)	13 (26)	8.6 (17)
Noncatalytic						
Conventional						
g/hr	34	210	2.3[d]	0.2	36	33
g/kg (lb/ton)	20 (39)	140 (270)	1.4[d]	0.2 (0.4)	32 (64)	14 (28)
Low emitting						
g/hr	-	180	-	0.2	-	-
g/kg (lb/ton)	-	130 (260)	-	0.2 (0.4)	-	-
Pellet fired						
g/hr	-	22	12[f]	0.2	-	-
g/kg (lb/ton)	-	18 (36)	6.9[f]	0.2 (0.4)	-	-

[a] References 1-6. Based on stove certification tests and test method comparison studies using EPA style tests and Douglas fir dimension lumber arranged in cribs. Emissions weighted using probability weighting scheme of EPA Method 28. Units are g/hr burning time and g/kg (lb/ton) wood consumed. Dash = data to be supplied upon review of field studies.

[b] Reference 1. Emission Factor Rating for particulate and carbon monoxide: C; for nitrogen oxides: E.

[c] Reference 14. Defined as total catch by EPA Method 5H (Oregon Method 7) train.

[d] References 1-13. Emission Factor Rating: C.

[e] References 5-6. Calculated by adding C_1-C_7 or C_2-C_7 data to total chromatographable organics. Emission Factor Rating: E.

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1.11 WASTE OIL COMBUSTION

1.11.1 General

"Waste oil" or "used oil" refers to spent lubricating and other industrial oils that are recovered for reuse as fuels, road oils and processed oils. The principal type of waste oil is used vehicle crankcase oil recovered by automobile service stations and waste oil collection depots. Other types of waste oil include metal working lubricants, heavy hydrocarbon fuels, animal and vegetable oils and fats, and industrial oils, including those used as transformer and other heat transfer fluids. Common contaminants in waste oils include metals, halogens, various volatile organic compounds (VOC) and solvents, and sulfur. Lead is found in appreciable quantities in used crankcase oil because of the use of tetraalkyllead gasoline additives. Many other metals and sulfur are introduced directly during formulation of lubricating oils as components of additives. Also, metals can be introduced through abrasion and wear of lubricated parts and surfaces. Halogens are introduced from the use of organic halides as lead scavengers in gasoline, or through commingling of waste oils and cleaning solvents such as perchloroethylene. Commingling of used oil and other organic compounds during collection and storage appears to be a common occurrence, as evidenced by the large number of relatively low molecular weight organics frequently found in used oils but not present in the original oils.[1]

In 1983, over 8.7 billion liters (2.3 billion gallons) of automotive and industrial lubricating oils and other industrial oils were sold.[1-2] Of this total, 4.6 billion liters (1.2 billion gallons) were recovered as used oil and subsequently reused or disposed of. The remainder was lost through engine breakdown during engine operation, end use application, leakage and handling. Waste oil combustion consumed 2.2 billion liters (0.59 billion gallons), or roughly half of the recovered total, up appreciably from 1970 estimates because of higher fuel costs, past fuel shortages, and the decline of other outlets for used oil, such as road oilant or base stock for re-refining.[3]

Waste oil may be burned alone or mixed with other fuel oil, in most conventional oil burning combustion systems. Several problems are associated with waste oil combustion, including reduced combustion efficiency and the corrosion and erosion of system components. However, these problems are not felt to be serious, and they can be reduced if the waste oil is blended with fuel oil or if the used oil is treated to reduce sediment, water, light end and metal content.[4] Metal emissions can be reduced if a vaporizing burner rather than an atomizing burner is used in small waste oil space heaters.

1.11.2 Emissions

Emission factors for uncontrolled waste oil combustion are presented in Table 1.11-1. Lead emissions depend on the oil's lead content and on boiler and burner design and operating conditions. Because of greatly decreased use of lead in gasoline, the lead content of waste oil has dropped significantly, falling from 10,000 parts per million in 1970 to 1,100 parts per million in 1982-83 and to 300 - 500 parts per million in 1985.[2-3] While further decreases

TABLE 1.11-1. EMISSION FACTORS FOR UNCONTROLLED WASTE OIL COMBUSTION[a]

Pollutant	Cut diameter (um)	Commercial/industrial boiler			Space heater[b]					
					Air atomizing burner			Vaporizing burner		
		Emissions		Emission Factor Rating	Emissions		Emission Factor Rating	Emissions		Emission Factor Rating
		(kg/m^3)	($lb/10^3$ gal)		(kg/m^3)	($lb/10^3$ gal)		(kg/m^3)	($lb/10^3$ gal)	
PM_{10}[c]	0.625	3.3(A)	27(A)	C	3.0(A)	25(A)	E	NA	NA	
	1.0	3.9(A)	32(A)		3.7(A)	31(A)				
	1.25	4.2(A)	35(A)		4.1(A)	34(A)				
	2.5	4.9(A)	41(A)		5.2(A)	44(A)				
	6.0	5.7(A)	48(A)		6.3(A)	52(A)				
	10.0	6.1(A)	51(A)		6.8(A)	57(A)				
	15.0	6.4(A)	54(A)		7.0(A)	58(A)				
Total particulate[d]		7.3(A)	61(A)	C	7.7(A)	64(A)	D	0.3(A)	2.4(A)	D
Lead[e]		5.0(P)	42(P)	C	6.1(P)	51(P)	D	0.07(P)	0.6(P)	D
Sulfur dioxide[f]		18(S)	147(S)	C	18(S)	147(S)	D	18(S)	147 (S)	D
Nitrogen oxides[g]		2.4	20	C	2.4	20	D	2.4	20	D
Carbon monoxide[h]		0.6	5	C	0.6	5	D	0.6	5	D
Volatile organic compounds[j]		0.12	1	D	0.12	1	D	0.12	1	D
Hydrochloric acid[k]		8(C)	66(C)	C	NA	NA		NA	NA	

[a] Factors are for unblended and untreated waste oil. Blending with fuel oil will reduce Pb, particulate, SO_2 and HCl emissions, directly related to fuel ash, Pb, and Cl contents, respectively. NO_x emissions may be reduced if overall fuel N is reduced by blending. Most "untreated" fuel oils will have undergone sedimentation to remove most bottom sediment and water. Filtration or centrifugation can reduce ash and Pb up to 30% and reduce particulate and Pb emissions accordingly. However, pretreatment will have little or no effect on emissions of other pollutants.

[b] References 3,10-12.

[c] References 3,8. Expressed as aerodynamic equivalent diameter. Based on overall particulate emission factors of 7.3(A) kg/m^3 [61(A) lb/10 gal] for commercial/industrial boilers and 7.7(A) kg/m^3 [64(A) lb/10 gal] for air atomizing space heaters.

[d] References 3,6-12. Defined as that material collected by EPA Method 5 (front half catch). (A) is weight % of ash in oil, and should be multiplied by value given. A typical concentration of ash in waste oil is 0.65%.

[e] References 3,6-12. Defined as elemental portion of particulate collected by EPA Method 5 (front half catch). (P) is weight % of Pb in oil, and should be multiplied by value given. A typical concentration of Pb in waste oil was 0.04% in January 1986, expected to decrease over time.

[f] References 9-10. (S) is weight % of S in oil, and should be multiplied by value given. A typical concentration of S in waste oil is 0.5%. Represents 98% transfer of S (as SO_2) from oil to flue gas, for oil with density of 900 kg/m^3 (7.5 lb/gal).

[g] References 9-10. Expressed as NO_2. Data are not sufficient to relate emissions to boiler type or fuel N content.

[h] References 8-10.

[j] References 9-11.

[k] Reference 8. (C) is weight % of Cl in oil, and should be multiplied by value given.

are forecast, the current lead content is still appreciably higher than the up to 100 parts per million levels found in conventional fuels. Typically, 50 percent or more of the lead in waste oil is emitted with flue gas during combustion, with the remainder deposited on internal surfaces.[3,5-10] However, in small space heaters employing vaporizing burners, less than 5 percent of the lead in the waste oil is emitted.[3]

Cumulative size distribution data and size specific emission factors for uncontrolled particulate emissions from waste oil combustion in commercial or industrial boilers and air atomizing space heaters are presented in Tables 1.11-2 and 1.11-3. Uncontrolled size specific emission factors are presented in Figures 1.11-1 and 1.11-2. Particulate emissions are based on the ash content of the fuel. Because the ash content of waste oil is generally higher than that found in refined oils, emissions from waste oil combustion will be greater.

Emissions of other pollutants, such as sulfur dioxide (SO_x) and hydrochloric acid (HCl), will depend on the respective sulfur and chlorine levels in the oil. Because levels of these precursor materials are generally greater in waste oils than in refined fuel oils, particularly distillate oil, waste oil combustion will produce more emissions of SO_x and HCl. In contrast, emissions of nitrogen oxides (NO_x), carbon monoxide (CO) and VOCs are similar for both waste and refined fuels.

1.11.3 Controls

Pretreatment - Most waste oil now sold as a fuel receives some sort of physical pretreatment (e. g., sedimentation, filtration, centrifugation, water and light end distillation). Lead and other trace element concentrations and the ash content of the waste oil generally will be lowered somewhat by some of these pretreatments, probably less than 30 percent. While lead and ash content reduction will reduce emissions of lead and particulate matter proportionately, its purpose is to reduce water, sediment and low boiling components. This provides a safely handled fuel with combustion properties similar to those of conventional fuels and with physical properties resembling a No. 4 fuel.[3] Thus, criteria pollutant emissions primarily affected by overall combustion efficiency (carbon monoxide and VOCs) will be similar to those from conventional fuels.[6]

Other criteria pollutants, such as sulfur and NO_x which depend either totally or partially on the fuel sulfur and nitrogen contents, will be emitted at levels consistent with those concentrations. Fuel sulfur and nitrogen levels generally do not decline with pretreatment. Because waste oil sulfur usually contains more sulfur than does distillate oil, emission factors for its combustion will be proportionally higher. Similarly, the higher nitrogen content of the waste oil can be expected to result in higher nitrogen oxide emissions. Emissions of chloride will be directly related to the chlorine content of the fuel, with 80 to 90 percent of the chlorine emitted as HCl.[8-9] Many chlorinated organics, such as the low molecular weight chlorinated solvents, will be removed during pretreatments employing light end distillation. However, chlorine bearing compounds with vapor pressures similar to those of the virgin base stock (e. g., polychlorinated biphenyls) will not be removed by this pretreatment. Expensive hydrofinishing, or possibly clay contacting operations, must be used to remove such chlorine.

TABLE 1.11-2. CUMULATIVE SIZE DISTRIBUTION FOR UNCONTROLLED PARTICULATE EMISSIONS AND SIZE SPECIFIC EMISSION FACTORS FOR COMMERCIAL/INDUSTRIAL BOILERS FIRING WASTE OIL[a]

Particle size[b] (um)	Cumulative mass % ≤ stated size	Emission factor[c] (kg/m^3)	(lb/10^3 gal)
15	88	6.4(A)	54(A)
10	84	6.1(A)	51(A)
6	78	5.7(A)	48(A)
2.5	67	4.9(A)	41(A)
1.25	57	4.2(A)	35(A)
1.00	53	3.9(A)	32(A)
0.625	45	3.3(A)	27(A)

[a] Reference 1. A = ash content in fuel.

[b] Expressed as aerodynamic equivalent diameter.

[c] Based on an overall particulate emission factor of 7.3(A) kg/m^3 [61(A) lb/10^3 gal].

TABLE 1.11-3. CUMULATIVE SIZE DISTRIBUTION FOR UNCONTROLLED PARTICULATE EMISSIONS AND SIZE SPECIFIC EMISSION FACTORS FOR AN AIR ATOMIZING SPACE HEATER UNIT FIRING WASTE OIL[a]

Particle size[b] (um)	Cumulative mass % ≤ stated size	Emission factor[c] (kg/m^3)	(lb/10^3 gal)
15	91	7.0(A)	58(A)
10	89	6.8(A)	57(A)
6	82	6.3(A)	52(A)
2.5	68	5.2(A)	44(A)
1.25	53	4.1(A)	34(A)
1.00	48	3.7(A)	31(A)
0.625	39	3.0(A)	25(A)

[a] Reference 5. A = ash content in fuel.

[b] Expressed as aerodynamic equivalent diameter.

[c] Based on an overall particulate emission factor of 7.7(A) kg/m^3 [64(A) lb/10^3 gal].

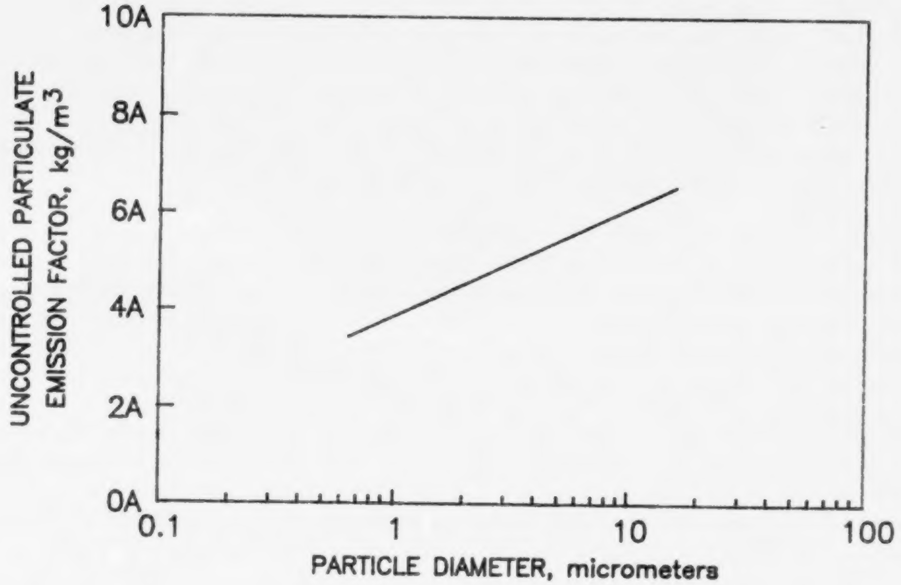

Figure 1.11-1. Cumulative size specific particulate emission factors for commercial/industrial boilers firing waste oil.

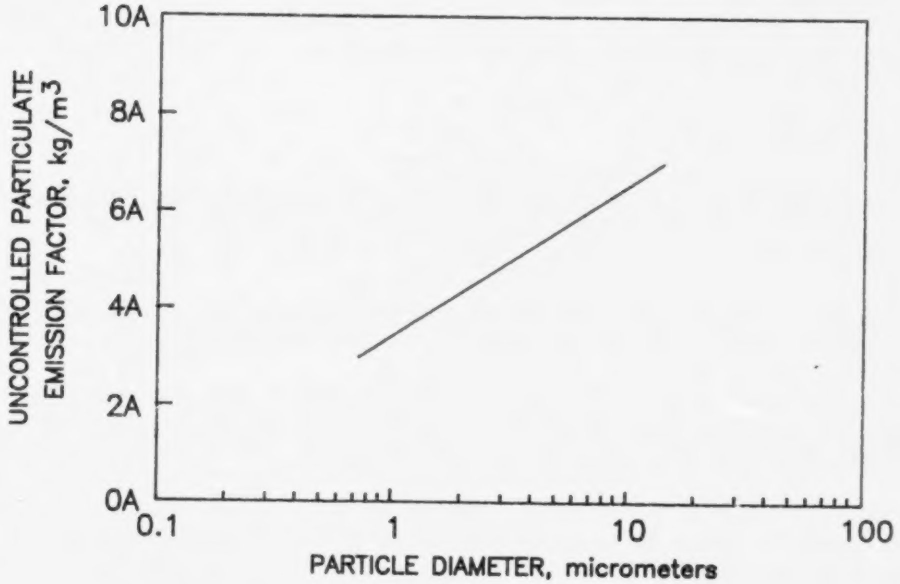

Figure 1.11-2. Cumulative size specific particulate emission factors for an air atomizing space heater unit firing waste oil.

Blending - Blending waste fuel and virgin fuel oil generally will reduce emissions of lead, particulate, sulfur dioxide and hydrochloric acid. Emissions of these pollutants will be approximately proportional to the respective concentrations of lead, ash, sulfur and chlorine in the blended fuel. NO_x emissions may also be reduced, although available data do not support a reduction estimate. Emissions of VOC and carbon monoxide, which depend on combustion efficiency, will not be significantly affected by blending.

Unit Design - There has been an increase in the use of waste oil as a fuel in small space heaters (those with less than 250,000 British Thermal Units per hour input).[8,10] Two types of burners are employed in these combustion systems, air atomizing and vaporizing. The conventional air atomizer injects aerosolized oil vapor into the combustion chamber, whereas the vaporizing burner operates through volatilization of heated oil. In the latter, the vapors are burned, and a residue is left behind in the vaporizing pot. The atomizing units emit at least an order of magnitude more particulate, lead and trace elements than do the vaporizing units. Although levels of VOC and other unburned combustible emissions appear comparable from both types of units, limited data suggest a significantly higher level of polycyclic organic matter emitted from vaporizing burners.

Control Equipment - Apart from the measure of control introduced by pretreatment, blending or the use of vaporizing burners, no additional controls are being applied to waste oil combustion. Waste oils are usually burned in small devices, for which controls are virtually nonexistent. Because greater than 80 percent of the lead bearing particulate is submicron in diameter, only high efficiency control devices such as fabric filters can provide significant control. Mechanical collectors will achieve little if any measurable control, either of lead emissions or of the submicron fraction of the particulate (about 55 percent) emitted in flue gas.[8]

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2.1 REFUSE COMBUSTION

Refuse combustion generally means the burning of predominantly nonhazardous garbage or other wastes. Types of combustion devices used to burn refuse include single chamber units, multiple chamber units, trench incinerators, controlled air incinerators, and pathological incinerators. These devices are used to burn municipal, commercial, industrial, pathological, and domestic refuse.

2.1.1 Municipal Waste Combustion[1]

Mass burn excess air combustion is the predominant method of burning municipal solid waste (MSW). Approximately 70 percent of the MSW burned is burned in mass burn units. The term "mass burn" means the burning of MSW without any prior processing other than the removal of bulky items (stoves, telephone poles, etc.) to produce a more homogeneous fuel. Mass burn units are preferred for disposal of large amounts (up to 2700 megagrams metric tons [3000 tons] per day) of MSW. Some mass burn units coincinerate MSW and sewage sludge. A second type of municipal waste combustor is the starved air or modular combustor. Starved air combustors are the most common type of combustor because they handle smaller amounts (up to 450 megagrams [500 tons] per day) of MSW. Another type of municipal waste combustor is the refuse-derived fuel (RDF) combustor. Refuse-derived fuel combustors burn MSW from which metals and other noncombustible materials have been removed. Because of the processing costs associated with producing RDF, these units are not as popular as mass burn or starved units. Some RDF is incinerated with coal or sewage sludge.

2.1.2 Process Description[1-3]

Mass Burn Combustors - Typically, an overhead crane mixes MSW in a storage pit and then moves it into a feed chute. A hydraulic ram system under the feed chute charges the waste onto a grate system. As the waste is moved through the combustion chamber by the grate system, it passes through three zones: a dryout zone, where moisture in the waste is evaporated; a combustion zone; and a burnout zone, where final combustion occurs. The resulting ash falls into a flooded ash pit and is removed and sent to a landfill. In some cases, ferrous metals are removed from the ash by magnetic separation. The capacity of individual combustors can range from 50 to 1000 megagrams of waste per day, and usually 2 or 3 units are at a site.

Several types of grate systems are used with mass burn combustors. They are all similar in being designed to move the waste through the combustor and to promote complete combustion. The grates can be traveling, rocking, reciprocating, roller, or rotary designs. The combustion process is supplied with underfire air, which is introduced into multiple compartments, or plenums, under the stoker grates, and with overfire air from nozzles or openings above the grates.

New mass burn combustors can be expected to have a water wall furnace to recover energy in the form of steam. Many older facilities have refractory lined walls rather than water walls. Large mass burn units are usually field erected.

The air pollution control systems for these combustors are electrostatic precipitators (ESP), dry fabric filters (FF), dry scrubbing systems (with either ESPs or FFs), and wet scrubbers.

Starved Air Combustors - A typical such unit has separate primary and secondary chambers. The primary chamber is fed MSW by a hopper and ram feed system. Air is supplied to the primary chamber at substoichiometric levels. Rams in the primary chamber push residue and break up clinker. Exhaust gases, including incomplete combustion products, (mostly carbon monoxide and hydrocarbons of low molecular weight) pass into the secondary combustion chamber.

In the secondary combustion chamber, more air is added, and combustion is completed. The resulting hot gases, 1000° to 1200°C (1800° to 2200°F), can be passed through a heat recovery boiler for energy recovery, and all new starved air combustors can be expected to have such systems. Ashes are quenched and removed for disposal. Most existing starved air municipal waste combustors operate without emission control systems, although some have ESPs or fabric filters for particulate control. Starved air combustors generally are available on the market and can be installed relatively quickly.

Refuse-derived Fuel Combustors - An alternative to direct combustion of MSW is processing the waste to produce refuse-derived fuel (RDF). The four main types of RDF are fluff, densified, powdered, and wet pulped. Fluff RDF is prepared by mechanical shredding of MSW, followed by air classification, magnetic separation, or trommeling to reduce the noncombustible content of the waste stream. If multiple shredding stages are used, fine RDF is produced. Densified RDF is fine RDF extruded in a pellet mill. Production of powdered RDF requires mechanical, thermal and chemical processing of shredded MSW that has undergone screening and magnetic separation. In the wet pulping process, the pulper is fed wet MSW that has been sluiced with water. Noncombustibles are removed in a liquid cyclone, then the RDF is then mechanically dewatered to a moisture content of 50 percent.

Boilers dedicated to RDF combustion are of basically the same design as those used for coal combustion. Typical configurations include suspension, stoker, and fluidized bed designs. These boilers may burn up to 900 megagrams (1000 tons) of RDF per day. The ash is quenched and removed to a landfill. Most RDF units use ESPs for particulate matter control.

2.1.3 Emissions And Controls[3-4]

Refuse incinerators have the potential to emit significant quantities of pollutants to the atmosphere. One of these pollutants is particulate matter, emitted because of the turbulent movement of the combustion gases with respect to the burning sludge and resultant ash. Particulate matter is also produced when metals that are volatilized in the combustion zone condense in the exhaust gas stream. Particle sizes and particulate concentrations leaving the incinerator vary widely, depending on the composition of the refuse being burned and on the type and operation of the incineration process.

Incomplete combustion of refuse, through improper incinerator design or operating conditions, can result in emissions of intermediate products such as volatile organic compounds and carbon monoxide. Other potential emissions include sulfur dioxide, nitrogen oxides, metals, acid gases, and toxic organic compounds.

A wide variety of control technologies is used to control refuse incinerator emissions. Currently, the most widely used devices are ESPs, fabric filters, wet scrubbers and dry scrubbers. Many control systems use a combination of these.

Electrostatic precipitators are used on 75 percent of existing municipal waste incinerators, to control particulate emissions. The efficiency of a typical ESP can range from 90 to 99 percent, depending on particle size distribution, gas flow rate and particle resistivity.

Fabric filters generally have not been applied directly to flue gases from municipal incinerators, but rather are used as sorbent collectors and secondary reactors for dry and semidry scrubbers. With upstream scrubbing of acid gases and sorbent accumulation on fabric materials, fabric filters become a viable choice for control of fine particulate as well as other pollutants.

Many types of wet scrubbers are used for removing acid gases - spray towers, centrifugal scrubbers and venturi scrubbers. Scrubbers with internals, such as packed beds and trays, are less commonly used. In wet scrubbers, the exhaust gas enters the absorber and contacts enough alkaline solution to saturate the gas stream. The alkaline solution reacts with the acid gases to form salts, which are generally insoluble and removable by sequential clarifying, thickening and vacuum filtering. The dewatered salts or sludges are then used as landfill.

The two types of dry scrubbing are dry injection and semidry scrubbing. In both, the material collected in the particle collector is dry. Dry injection is the injection of a solid powder such as lime or sodium bicarbonate into the flue gas (with a separate water injection). Acid gas removal occurs in the duct and continues in the dust collector, as sorbent and ash particles and condensed volatile matter are captured. In a semidry process, also known as spray drying or wet/dry scrubbing, the sorbent enters the flue gas as a liquid spray, with sufficient moisture to promote rapid absorption of acid gases, but, because the moisture evaporates, only dry solid particles collector.

Emission factors for municipal waste incinerators are shown in Table 2.1-1. Table 2.1-2 shows the cumulative particle size distribution and size specific emission factors for municipal waste combustors. Figures 2.1-1, 2.1-2 and 2.1-3 show the cumulative particle size distribution and size specific emission factors for mass burn, starved air and RDF combustors, respectively.

2.1.4 Other Types Of Combustion[2,5-7]

The most common types of combustors have a refractory lined chamber with a grate upon which refuse is burned. In some newer incinerators, water walled furnaces are used. Combustion products are formed by heating and burning refuse on the grate. In most cases, since insufficient underfire air is provided to complete combustion, additional air is admitted above the burning waste to promote complete gas phase combustion. In multiple chamber incinerators, gases from the primary chamber flow to a small secondary mixing chamber, where more air is admitted and more extensive oxidation occurs. As much as 300 percent

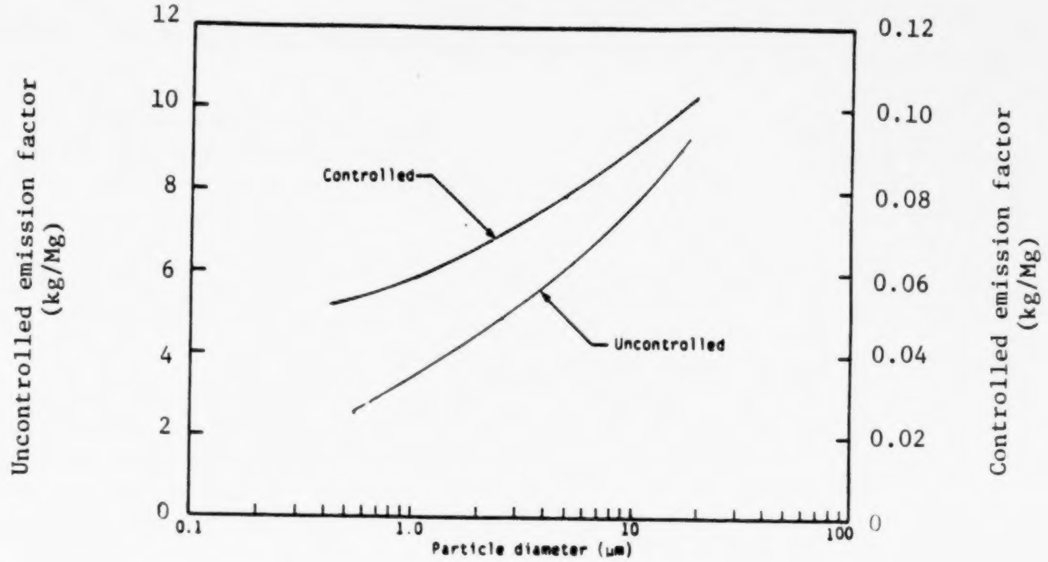

Figure 2.1-1. Cumulative particle size distribution and size specific emission factors for mass burn combustors.

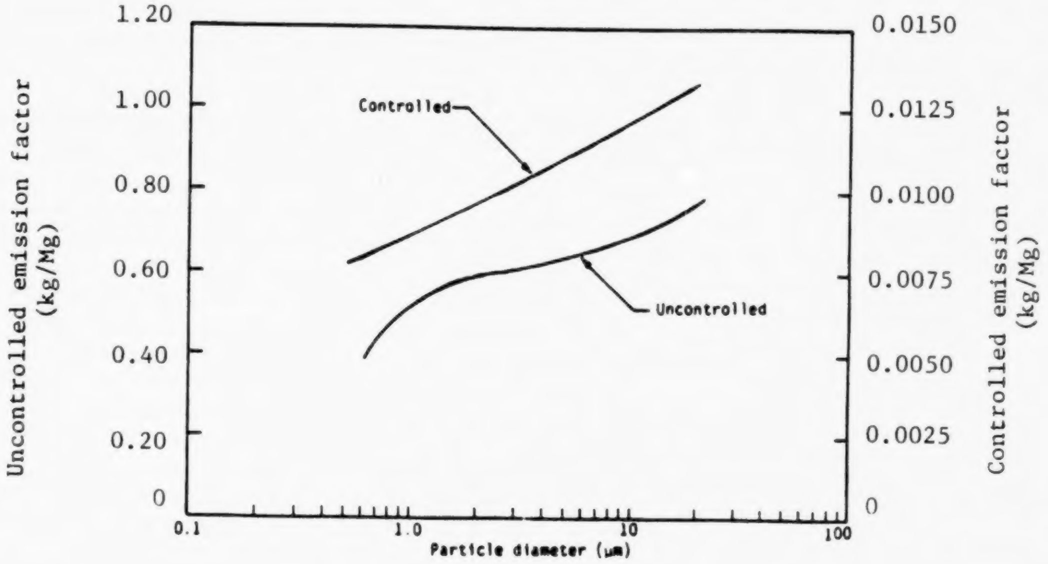

Figure 2.1-2. Cumulative particle size distribution and size specific emission factors for starved air combustors.

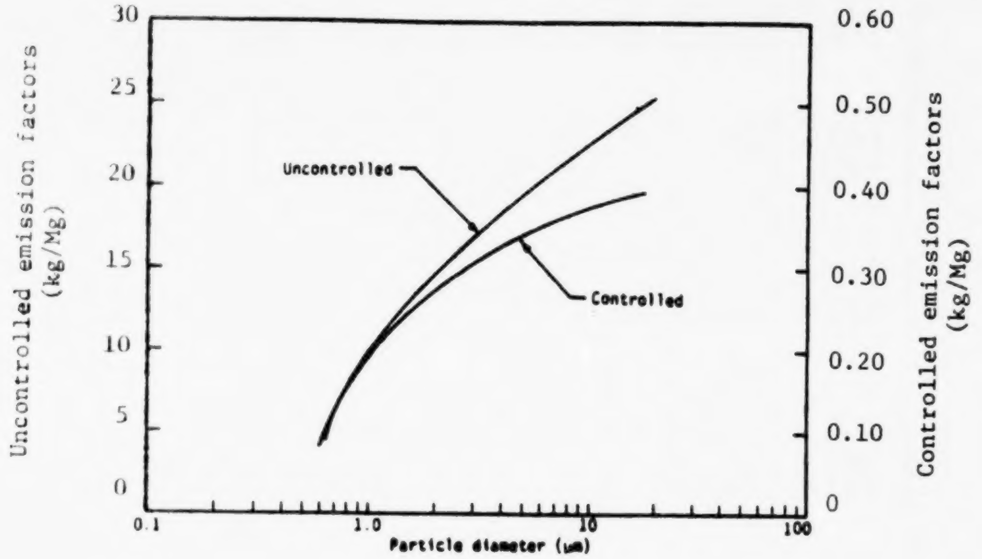

Figure 2.1-3. Cumulative particle size distribution and size specific emission factors for refuse-derived fuel combustors.

excess air may be supplied in order to promote oxidation of combustibles. Auxiliary burners are sometimes installed in the mixing chamber to increase the combustion temperature. Many small incinerators are single chamber units in which gases vent from the primary combustion chamber directly into the exhaust stack. Single chamber incinerators of this type do not meet modern air pollution codes.

2.1.5 Process Description[2,5-7]

Industrial/Commercial Combustors - The capacities of these units cover a wide range, generally between 23 and 1800 kilograms (50 and 4000 pounds) per hour. Of either single or multiple-chamber design, these units are often manually charged and intermittently operated. Some industrial combustors are similar to municipal combustors in size and design. Better designed emission control systems include gas fired afterburners, scrubbers, or both.

Trench Combustors - A trench combustor is designed to handle wastes of relatively high heat content and low ash content. The design is a simple U-shaped combustion chamber formed by the sides and bottom of the pit, and air is supplied from nozzles (or fans) along the top of the pit. The nozzles are directed at an angle below the horizontal, to provide a curtain of air across

TABLE 2.1-1. EMISSION FACTORS FOR MUNICIPAL WASTE COMBUSTION[a]

Pollutant	Particle diameter (ug)	Mass Burn Uncontrolled kg/Mg (lb/ton)	Mass Burn Controlled kg/Mg (lb/ton)	Mass Burn Emission Factor Rating	Starved Air Uncontrolled kg/Mg (lb/ton)	Starved Air Controlled kg/Mg (lb/ton)	Starved Air Emission Factor Rating	Refuse-derived Fuel Uncontrolled kg/Mg (lb/ton)	Refuse-derived Fuel Controlled kg/Mg (lb/ton)	Refuse-derived Fuel Emission Factor Rating
PM_{10}	0.625	2.7 (5.4)	0.055 (0.11)[b]	C	0.40 (0.80)	0.0080 (0.016)[b]	D	4.4 (8.8)	0.090 (0.18)[c]	E
	1.0	3.5 (7.0)	0.065 (0.13)		0.50 (1.0)	0.0095 (0.019)		10 (20)	0.19 (0.38)	
	2.5	4.6 (9.2)	0.075 (0.15)		0.60 (1.2)	0.010 (0.020)		16 (32)	0.29 (0.58)	
	5.0	6.0 (12)	0.080 (0.16)		0.65 (1.3)	0.011 (0.022)		21 (42)	0.36 (0.72)	
	10.0	7.0 (14)	0.090 (0.18)		0.70 (1.4)	0.012 (0.024)		22 (44)	0.37 (0.74)	
	15.0	9.0 (18)	0.10 (0.20)		0.75 (1.5)	0.013 (0.026)		24 (48)	0.39 (0.78)	
Total Particulate		19 (38)	0.19 (0.38)[b]	C	0.95 (1.9)	0.015 (0.030)[b]	D	40 (80)	0.04 (0.08)[c]	D
Lead		0.09 (0.18)	0.011 (0.022)[b]	C	0.06 (0.12)	0.001 (0.002)[b]	D	0.065 (0.13)	0.014 (0.028)[c]	D
Sulfur Dioxide[d]		0.85 (1.7)	0.55 (1.1)[e]	D	0.85 (1.7)	0.55 (1.1)[e]	D	0.85 (1.7)	0.55 (1.1)[e]	D
Nitrogen Oxides		1.8 (3.6)	1.8 (3.6)[c]	D	2.2 (4.4)	2.2 (4.4)[c]	D	2.5 (5.0)	2.5 (5.0)[c]	D
Carbon Monoxide		1.1 (2.2)	1.1 (2.2)[e]	D	0.17 (3.4)	0.17 (3.4)[c]	D	1.8 (3.6)	1.8 (3.6)[b]	D
Volatile Organic Compounds										
Methane		0.0032 (0.0064)	0.0032 (0.0064)[b]	D	NA	NA		NA	NA	
Nonmethane		0.05 (0.10)	0.05 (0.10)[b]	D	NA	NA		NA	NA	

[a] Reference 3. NA = not available.

[b] Control devices include ESPs and FFs.

[c] ESP.

[d] Average for all three combustor types.

[e] Control devices include ESPs, FFs, dry scrubbers, wet scrubbers.

TABLE 2.1-2. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR MUNICIPAL WASTE COMBUSTORS[a]

Particle Size (ug)	Cumulative mass % < stated size						Cumulative emission factor, kg/Mg (lb/ton)					
	Uncontrolled			Controlled			Uncontrolled			Controlled		
	MB	SA	RDF	MB	SA	RDF	MB	SA	RDF	MB	SA	RDF
15.0	47	79	60	53	87	71	9.0 (18)	0.75 (1.5)	24 (48)	0.10 (0.20)	0.013 (0.026)	0.39 (0.7)
10.0	37	74	55	47	80	67	7.0 (14)	0.70 (1.4)	22 (44)	0.090 (0.18)	0.012 (0.024)	0.37 (0.7)
5.0	32	68	53	42	73	65	6.0 (12)	0.65 (1.3)	21 (42)	0.080 (0.16)	0.011 (0.022)	0.36 (0.7)
2.5	24	63	40	39	67	53	4.6 (9.2)	0.60 (1.2)	16 (32)	0.075 (0.15)	0.010 (0.020)	0.29 (0.5)
1.0	18	53	25	34	63	35	3.5 (7.0)	0.50 (1.0)	10 (20)	0.065 (0.13)	0.0095 (0.019)	0.19 (0.3)
0.625	14	42	11	29	53	16	2.7 (5.4)	0.40 (0.80)	4.4 (8.8)	0.055 (0.11)	0.0080 (0.016)	0.09 (0.1)
Total	100	100	100	100	100	100	19 (38)	0.95 (1.9)	40 (80)	0.19 (0.38)	0.015 (0.030)	0.55 (1.1)

[a] Reference 3. MB = mass burn. SA = starved air. DF = refuse-derived fuel.

TABLE 2.1-3. UNCONTROLLED EMISSION FACTORS FOR INDUSTRIAL/COMMERCIAL REFUSE COMBUSTORS[a]

EMISSION FACTOR RATING: A

Incinerator type	Particulate		Sulfur oxides[b]		Carbon monoxide		Volatile organics[c]		Nitrogen oxides[d]	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Multiple chambers[e]	3.5	7	1.25	2.5[f]	5	10	1.5	3	1.5	3
Single chamber[g]	7.5	15	1.25	2.5[f]	10	20	7.5	15	1	2
Trench[h]										
Wood	6.5	13	0.05	0.1[j]	NA	NA	NA	NA	2	4
Rubber tires	69	138	NA	NA	NA	NA	NA	NA	NA	NA
Municipal refuse	18.5	37	1.25	2.5[f]	NA	NA	NA	NA	NA	NA
Flue fed										
Single chamber[k]	15	30	0.25	0.5	10	20	7.5	15	1.5	3
Modified[m]	3	6	0.25	0.5	5	10	1.5	3	5	10
Domestic single chamber										
Without primary burner[n]	17.5	35	0.25	0.5	150	300	50	100	0.5	1
With primary burner[p]	3.5	7	0.25	0.5	Neg	Neg	1	2	1	2
Pathological[q]	4	8	Neg	Neg	Neg	Neg	Neg	Neg	1.5	3

[a] Factors are averages based on EPA procedures for incinerator stack testing. NA = not available. Neg = negligible.
[b] Expressed as SO_2.
[c] Expressed as methane.
[d] Expressed as NO_2.
[e] References 6,10-13.
[f] Based on municipal incinerator data.
[g] References 6,10-11,13.
[h] Reference 8.
[j] Based on data for wood combustion in conical burners.
[k] References 6,11-15.
[m] With afterburners and draft controls. References 6,13-14.
[n] References 10-11.
[p] Reference 10.
[q] Reference 6,16.

the top of the pit and to provide air for combustion in the pit. Low construction and operating costs have led to use of this combustor to dispose of materials other than those for which it was originally designed. Emission factors for trench combustors used to burn three such materials are given in Table 2.1.3.[8]

Domestic Combustors - This category includes combustors marketed for residential use. Fairly simple in design, they may have single or multiple chambers and usually are equipped with an auxiliary burner to aid combustion.

Flue Fed Combustors - These units, commonly found in large apartment houses, are characterized by the charging method of dropping refuse down the combustor flue and into the combustion chamber. Modified flue fed incinerators utilize afterburners and draft controls to improve combustion efficiency and to reduce emissions.

Pathological Combustors - These are combustors used to dispose of animal remains and other organic material of high moisture content. Generally, these units are able to process 23 to 45 kilograms (50 to 100 pounds) of such waste per hour. Wastes are burned on a hearth in the combustion chamber. The units are equipped with combustion controls and afterburners to ensure good combustion and reduced emissions.

2.1.6 Emissions And Controls[2,9]

Operating conditions, composition of refuse, and basic combustor design have a pronounced effect on emissions. The manner in which air is supplied to the combustion chamber or chambers has a significant effect on the quantity of particulate emissions. Air may be introduced from beneath, aside or atop the combustion chamber. As underfire air is increased, an increase in fly ash emissions occurs. Erratic refuse charging causes a disruption of the combustion bed and subsequent release of large quantities of particulate. Large amounts of uncombusted particulate and carbon monoxide also are emitted for an extended period after the charging of batch fed units, because of interruptions in the combustion process. In continuously fed units, furnace particulate emissions strongly depend on grate type. Use of a rotary kiln and reciprocating grates results in higher particulate emissions than does use of a rocking or traveling grate. Emissions of oxides of sulfur depend on the sulfur content of the refuse. Carbon monoxide and unburned hydrocarbon emissions may be significant, and are caused by poor combustion resulting from improper combustor design or operating conditions. Nitrogen oxide emissions increase with increases in combustion zone temperature, residence time in the combustion zone before quenching, and excess air rates to the point where dilution cooling overcomes the effect of increased oxygen concentration.[6]

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2.1.2 Other Types of Combustors[1-4]

The most common types of combustors consist of a refractory-lined chamber with a grate upon which refuse is burned. In some newer incinerators water-walled furnaces are used. Combustion products are formed by heating and burning of refuse on the grate. In most cases, since insufficient underfire (undergrate) air is provided to enable complete combustion, additional over-fire air is admitted above the burning waste to promote complete gas-phase combustion. In multiple-chamber incinerators, gases from the primary chamber flow to a small secondary-mixing chamber where more air is admitted, and more complete oxidation occurs. As much as 300 percent excess air may be supplied in order to promote oxidation of combustibles. Auxilliary burners are sometimes installed in the mixing chamber to increase the combustion temperature. Many small-size incinerators are single-chamber units in which gases are vented from the primary combustion chamber directly into the exhaust stack. Single-chamber incinerators of this type do not meet modern air pollution codes.

2.1.2.1 Process Description[1-4]

Industrial/Commercial Combustors--The capacities of these units cover a wide range. generally between 50 and 4,000 pounds (22.7 and 1,800 kilograms) per hour. Of either single- or multiple-chamber design, these units are often manually charged and intermittently operated. Some industrial combustors are similar to municipal combustors in size and design. Better designed emission control systems include gas-fired afterburners, scrubbers, or both.

Trench Combustors--A trench combustor is designed for the combustion of wastes having relatively high heat content and low ash content. The design of the unit is simple: a U-shaped combustion chamber is formed by the sides and bottom of the pit, and air is supplied from nozzles (or fans) along the top of the pit. The nozzles are directed at an angle below the horizontal to provide a curtain of air across the top of the pit and to provide air for combustion in the pit. Low construction and operating costs have resulted in the use of this combustor to dispose of materials other than those for which it was originally designed. Emission factors for trench combustors used to burn three such materials are included in Table 2.1.2-1.[5]

Domestic Combustors--This category includes combustors marketed for residential use. Fairly simple in design, they may have single or multiple chambers and usually are equipped with an auxiliary burner to aid combustion.

Flue-Fed Combustors--These units, commonly found in large apartment houses, are characterized by the charging method of dropping refuse down the combustor flue and into the combustion chamber. Modified flue-fed incinerators utilize afterburners and draft controls to improve combustion efficiency and reduce emissions.

Pathological Combustors--These are combustors used to dispose of animal remains and other organic material of high moisture content. Generally, these units are in a size range of 50 to 100 pounds (22.7 to 45.4 kilograms)

TABLE 2.1.2-1. EMISSION FACTORS FOR REFUSE COMBUSTORS OTHER THAN MUNICIPAL WASTE WITHOUT CONTROLS[a] EMISSION FACTOR RATING: A

Incinerator type	Particulate		Sulfur oxides[b]		Carbon monoxide		Hydrocarbons[c]		Nitrogen oxides[d]	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Industrial/commercial										
Multiple chambers[e]	7	3.5	2.5[f]	1.25	10	5	3	1.5	3	1.5
Single chamber[g]	15	7.5	2.5[f]	1.25	20	10	15	7.5	2	1
Trench[h]										
Wood	13	6.5	0.1[i]	0.05	j	j	j	j	4	2
Rubber tires	138	69	j	j	j	j	j	j	j	j
Municipal refuse	37	18.5	2.5[f]	1.25	j	j	j	j	j	j
Flue-fed single chamber[k]	30	15	0.5	0.25	20	10	15	7.5	3	1.5
Flue-fed (modified)[l,m]	6	3	0.5	0.25	10	5	3	1.5	10	5
Domestic single chamber										
Without primary burner[n]	35	17.5	0.5	0.25	300	150	100	50	1	0.5
With primary burner[o]	7	3.5	0.5	0.25	Neg.	Neg.	2	1	2	1
Pathological[p]	8	4	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	3	1.5

[a] Average factors given based on EPA procedures for incinerator stack testing.
[b] Expressed as sulfur dioxide.
[c] Expressed as methane.
[d] Expressed as nitrogen dioxide.
[e] References 3, 7, 8, 9, and 10.
[f] Based on municipal incinerator data.
[g] References 3, 7, 8, and 10.
[h] Reference 5.
[i] Based on data for wood combustion in conical burners.
[j] Not available.
[k] References 3, 8, 9, 10, 11, and 12.
[l] With afterburners and draft controls.
[m] References 3, 10, and 11.
[n] References 7 and 8.
[o] Reference 7.
[p] References 3 and 13.

per hour. Wastes are burned on a hearth in the combustion chamber. The units are equipped with combustion controls and afterburners to ensure good combustion and minimal emissions.

2.1.2.2 Emissions and Controls[1]

Operating conditions, refuse composition, and basic combustor design have a pronounced effect on emissions. The manner in which air is supplied to the combustion chamber or chambers has a significant effect on the quantity of particulate emissions. Air may be introduced from beneath the chamber, from the side, or from the top of the combustion chamber. As underfire air is increased, an increase in fly-ash emissions occurs. Erratic refuse charging causes a disruption of the combustion bed and a subsequent release of large quantities of particulates. Large quantities of uncombusted particulate matter and carbon monoxide are also emitted for an extended period after charging of batch-fed units because of interruptions in the combustion process. In continuously fed units, furnace particulate emissions are strongly dependent upon grate type. The use of a rotary kiln and reciprocating grates results in higher particulate emissions than the use of a rocking or traveling grate.[6] Emissions of oxides of sulfur are dependent on the sulfur content of the refuse. Carbon monoxide and unburned hydrocarbon emissions may be significant and are caused by poor combustion resulting from improper combustor design or operating conditions. Nitrogen oxide emissions increase with an increase in the temperature of the combustion zone, an increase in the residence time in the combustion zone before quenching, and an increase in the excess air rates to the point where dilution cooling overcomes the effect of increased oxygen concentration.[6]

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2.5 SEWAGE SLUDGE INCINERATION

2.5.1 Process Description[1-3]

In sewage sludge incineration, materials generated by wastewater treatment plants are oxidized to reduce the volume of solid waste.

In the first step in the process, the sludge is dewatered until it is 15 to 30 percent solids so that it will burn without auxiliary fuel. Dewatered sludge is conveyed to a combustion device where thermal oxidation occurs. The unburned residual ash is removed from the combustion device, usually on a continuous basis, and disposed. The exhaust gas stream is directed to an air pollution control device, typically a wet scrubber.

Approximately 95 percent of sludge incinerators are multiple-hearth and fluidized-bed designs. Multiple-hearth incinerators are vertically oriented cylindrical shells containing from 4 to 14 refractory hearths stacked one above the other. Sludge typically enters at the periphery of the top hearth and is raked inward by the teeth on a rotating rabble arm to a drop hole leading to the second hearth. The teeth on the rabble arm above the second hearth are positioned in the opposite direction to move the sludge outward. This outside-in, inside-out pattern is repeated on alternate hearths. Fluidized-bed incinerators also are vertically oriented cylindrical shells. A bed of sand approximately 0.7-meters (2.5-feet) thick rests on the grid and is fluidized by air injected through the tuyeres located at the base of the furnace within a refractory-lined grid. Sludge is introduced directly into the bed. Temperatures in a multiple-hearth furnace are 320°C (600°F) in the lower, ash-cooling hearth; 760° to 1100°C (1400° to 2000°F) in the central combustion hearths; and 540° to 650°C (1000° to 1200°F) in the upper, drying hearths. Temperatures in a fluidized-bed reactor are fairly uniform, from 680° to 820°C (1250° to 1500°F). In both types of furnaces, an auxiliary fuel may be required either during startup or when the moisture content of the sludge is too high to support combustion.

Electric (infrared) furnaces are the newest of the technologies currently in use for sludge incineration. The sludge is conveyed into one end of the horizontally oriented incinerator where it is first dried and then burned as it travels beneath the infrared heating elements.

Other sludge incineration technologies that are no longer in widespread use include cyclonic reactors, rotary kilns, and wet oxidation reactors. Some sludge is coincinerated with refuse.

2.5.2 Emissions and Controls[1,2,4]

Sludge incinerators have the potential to emit significant quantities of pollutants to the atmosphere. One of these pollutants is particulate matter, which is emitted because of the turbulent movement of the combustion gases with respect to the burning sludge and resultant ash. The particle size distribution and concentration of the particulate emissions leaving the incinerator vary widely, depending on the composition of the sludge being burned and the type and operation of the incineration process.

Total particulate emissions are usually highest for a fluidized-bed incinerator because the combustion gas velocities required to fluidize the bed result in entrainment of large quantities of ash in the flue gas. Particulate emissions from multiple-hearth incinerators are usually less than those from fluidized-bed incinerators because the agitation of ash and gas velocity through the bed are lower in the multiple-hearth incinerators. Electric furnaces have the lowest particulate matter emissions because the sludge is not stirred or mixed during incineration and air flows through the unit generally are quite low, resulting in minimal entrainment.

Incomplete combustion of sludge can result in emissions of intermediate products (e.g., volatile organic compounds and carbon monoxide). Other potential emissions include sulfur dioxide, nitrogen oxides, metals, acid gases, and toxic organic compounds.

Wet scrubbers are commonly used to control particulate and gaseous (e.g., SO_2, NOx, CO, and VOC's) emissions from sludge incinerators. There are two practical reasons for this: (1) a wastewater treatment plant is a source of relatively inexpensive scrubber water (plant effluent) and (2) a system for the treatment of the scrubber effluent is available (spent scrubber water is sent to the head of the treatment plant for solids removal and pH adjustment). The most widely used scrubber types are venturi and impingement-tray. Cyclone wet scrubbers and systems combining all three types of scrubbers are also used.

Pressure drops for venturi, impingement tray, and cyclone scrubbers are 1 to 40 kPa, 0.4 kPa per stage, and 1 to 2 kPa, respectively. Collection efficiency can range from 60 to 99 percent depending on the scrubber pressure drop, particle size distribution, and particulate concentration.

Emission factors and emission factor ratings for sludge incinerators are shown in Table 2.5-1. Table 2.5-2 shows the cumulative particle size distribution and size specific emission factors for sewage sludge incinerators. Figures 2.5-1, 2.5-2, and 2.5-3 show the cumulative particle size distribution and size-specific emission factors for multiple-hearth, fluidized-bed, and electric infrared incinerators, respectively.

TABLE 2.5-1. EMISSION FACTORS FOR SEWAGE SLUDGE INCINERATORS[a]

Pollutant	Cut diameter, microns	Multiple hearth			Fluidized bed			Electric infrared		
		Uncontrolled emissions, kg/Mg (lb/ton)[b]	After scrubber emissions, kg/Mg (lb/ton)[b]	Emission factor rating	Uncontrolled emissions, kg/Mg (lb/ton)[b]	After scrubber emissions, kg/Mg (lb/ton)[b]	Emission factor rating	Uncontrolled emissions, kg/Mg (lb/ton)[b]	After scrubber emissions, kg/Mg (lb/ton)[b]	Emission factor rating
PM_{10}	0.625	0.30 (0.60)	0.07 (0.14)[b]	D	NA	0.08 (0.16)[d]	D	0.50 (1.0)	0.30 (0.60)[e]	E
	1.0	0.47 (0.94)	0.08 (0.16)			0.15 (0.30)		0.60 (1.2)	0.35 (0.70)	
	2.5	1.1 (2.2)	0.09 (0.18)			0.18 (0.36)		1.0 (2.0)	0.50 (1.0)	
	5.0	2.1 (4.2)	0.10 (0.20)			0.20 (0.40)		1.7 (3.4)	0.70 (1.4)	
	10.0	4.1 (8.2)	0.11 (0.22)			0.22 (0.44)		3.0 (6.0)	1.0 (2.0)	
	15.0	6.0 (12)	0.12 (0.24)			0.23 (0.46)		4.3 (8.6)	1.2 (2.4)	
Total particulate		40 (80)	0.40 (0.80)[e]	C	NA	3.0 (6.0)[e]	C	10 (20)	2.0 (4.0)[e]	E
Lead		0.05 (0.10)	0.03 (0.06)[e]	C	NA	0.003 (0.006)[e]	D	NA	NA	
Sulfur dioxide[f]		10 (20)	2.0 (4.0)[e]	D	10 (20)	2.0 (4.0)[e]	D	10 (20)	2.0 (4.0)[e]	D
Nitrogen oxides		5.5 (11)	2.5 (5.0)[e]	C	NA	1.0 (2.0)[e]	D	4.3 (8.6)	3.0 (6.0)[e]	E
Carbon monoxide		30 (60)	2.0 (4.0)[e]	C	NA	2.1 (4.2)[e]	E	NA	NA	
Volatile organic compounds										
Methane		2.3 (4.6)	2.3 (4.6)[e]	D	0.80 (1.6)	0.80 (1.6)[e]	E	NA	NA	
Nonmethane		0.85 (1.7)	0.85 (1.7)[e]	D	NA	NA		NA	NA	

NA = not available.

[a] Reference 5.

[b] Unit expressed in terms of dried sludge.

[c] Impingement scrubber.

[d] Venturi scrubber.

[e] Impingement and venturi scrubbers.

[f] Because data were limited, an average for all three types of incinerators is presented.

TABLE 2.5-2. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR SEWAGE SLUDGE INCINERATORS[a]

Particle size, microns	Cumulative mass % ≤ stated size						Cumulative emission factor, kg/Mg (lb/ton)					
	Uncontrolled			Controlled			Uncontrolled			Controlled		
	MH[b]	Fb[c]	EI[d]	MH[b]	Pb[c]	EI[d]	MH[b]	Fb[c]	EI[d]	MH[b]	Fb[c]	EI[d]
15	15	NA	43	30	7.7	60	6.0 (12)	NA	4.3 (8.6)	0.12 (0.24)	0.23 (0.46)	1.2 (2.4)
10	10	NA	30	27	7.3	50	4.1 (8.2)	NA	3.0 (6.0)	0.11 (0.22)	0.22 (0.44)	1.0 (2.0)
5.0	5.3	NA	17	25	6.7	35	2.1 (4.2)	NA	1.7 (3.4)	0.10 (0.20)	0.20 (0.40)	0.70 (1.4)
2.5	2.8	NA	10	22	6.0	25	1.1 (2.2)	NA	1.0 (2.0)	0.09 (0.18)	0.18 (0.36)	0.50 (1.0)
1.0	1.2	NA	6.0	20	5.0	18	0.47 (0.94)	NA	0.60 (1.2)	0.08 (0.16)	0.15 (0.30)	0.35 (0.70)
0.625	0.75	NA	5.0	17	2.7	15	0.30 (0.60)	NA	0.50 (1.0)	0.07 (0.14)	0.08 (0.16)	0.30 (0.60)
TOTAL	100	100	100	100	100	100	40 (80)	NA	10 (20)	0.40 (0.80)	3.0 (6.0)	2.0 (4.0)

[a] Reference 5.
[b] MH = multiple hearth.
[c] FB = fluidized bed.
[d] EI = electric infrared.
NA = not available.

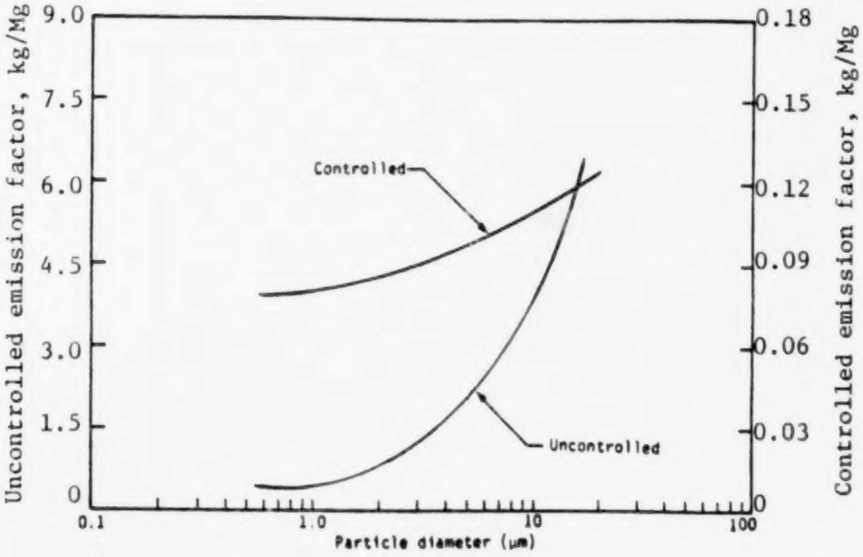

Figure 2.5-1. Cumulative particle size distribution and size-specific emission factors for multiple-hearth incinerators.

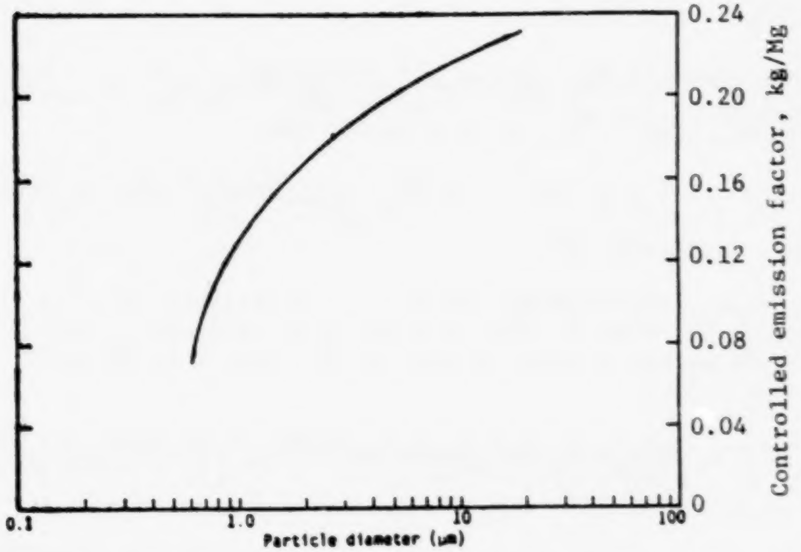

Figure 2.5-2. Cumulative particle size distribution and size-specific emission factors for fluidized-bed incinerators.

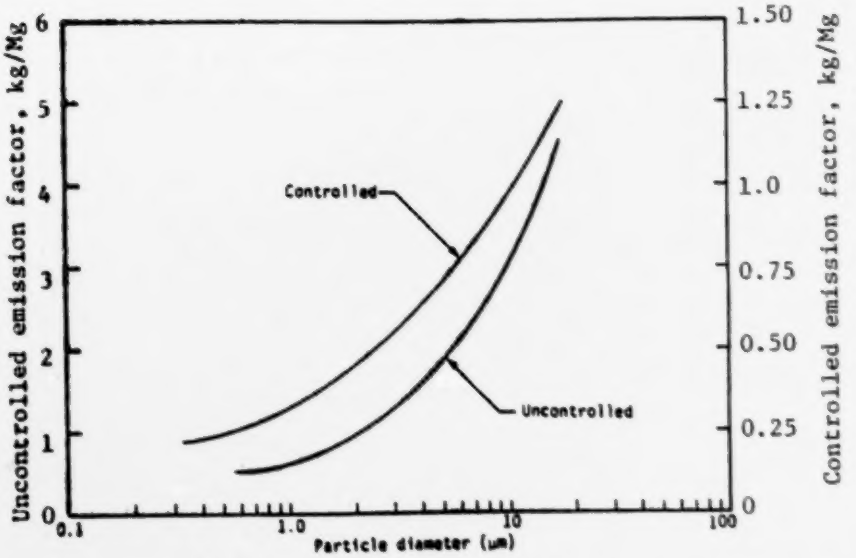

Figure 2.5-3. Cumulative particle size distribution and size-specific emission factors for electric (infrared) incinerators.

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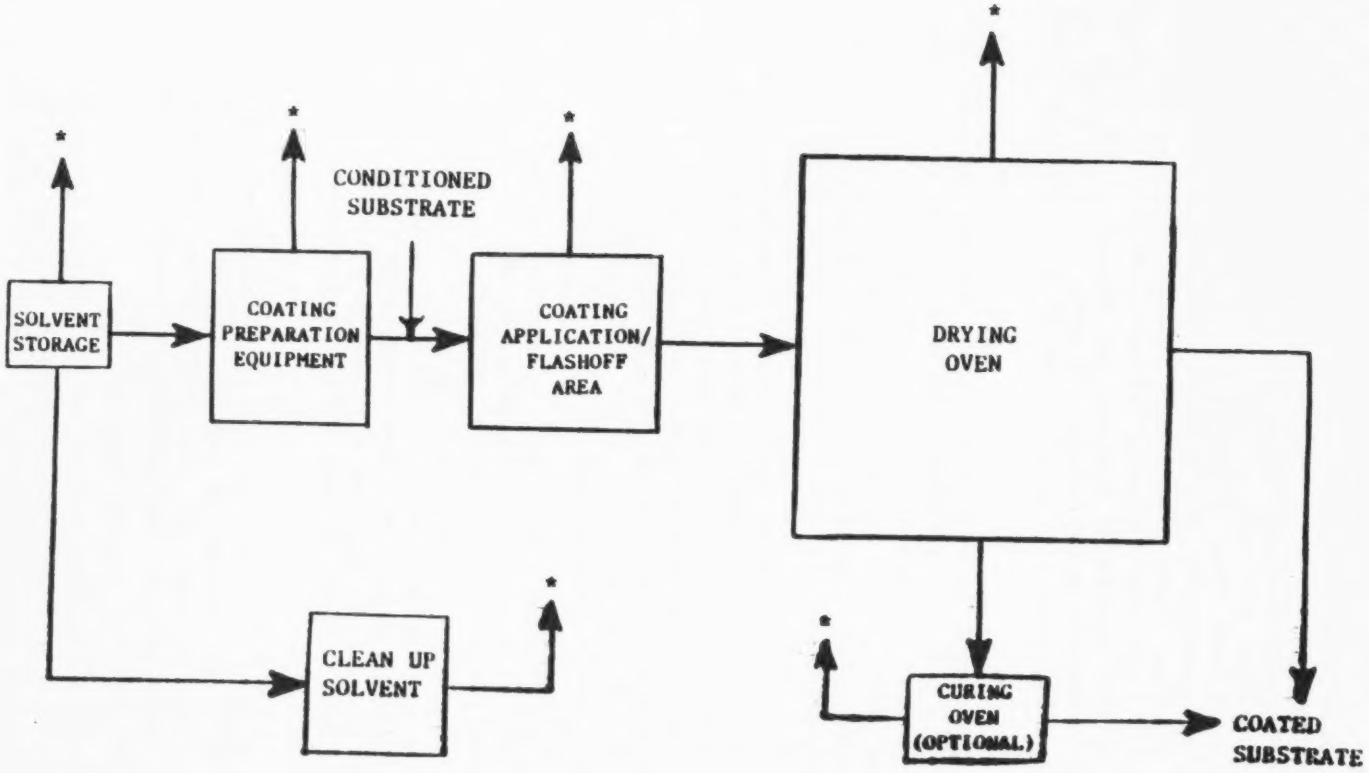
4.2.2.7 Polymeric Coating of Supporting Substrates[1-8]

"Polymeric coating of supporting substrates" is defined as a web coating process other than paper coating that applies an elastomer or other polymeric material onto a supporting substrate. Typical substrates include woven, knit, and nonwoven textiles; fiberglass; leather; yarn; and cord. Examples of polymeric coatings are natural and synthetic rubber, urethane, polyvinyl chloride, acrylic, epoxy, silicone, phenolic resins, and nitrocellulose. Plants have from 1 to more than 10 coating lines. Most plants are commission coaters where coated substrates are produced according to customer specifications. Typical products include rainwear, conveyor belts, V-belts, diaphragms, gaskets, printing blankets, luggage, and aircraft and military products. This industrial source category has been retitled from "Fabric Coating" to that listed above to reflect the general use of polymeric coatings on substrate materials including but not limited to conventional textile fabric substrates.

Process description[1-3] - The process of applying a polymeric coating to a supporting substrate consists of mixing the coating ingredients (including solvents), conditioning the substrate, applying the coating to the substrate, drying/curing the coating in a drying oven, and subsequent curing or vulcanizing if necessary. Figure 4.2.2.7-1 is a schematic of a typical solvent-borne polymeric coating operation identifying volatile organic compound (VOC) emission locations. Typical plants have one or two small (≤ 38 m^3 or 10,000 gallons) horizontal or vertical solvent storage tanks which are operated at atmospheric pressure, however, some plants have as many as five. Coating preparation equipment includes the mills, mixers, holding tanks, and pumps used to prepare polymeric coatings for application. Urethane coatings typically are purchased premixed and require little or no mixing at the coating plant. The conventional types of equipment for applying organic solvent-borne and waterborne coatings include knife-over-roll, dip, and reverse-roll coaters. Once applied to the substrate, liquid coatings are solidified by evaporation of the solvent in a steam-heated or direct-fired oven. Drying ovens usually are of forced-air convection design in order to maximize drying efficiency and prevent a dangerous localized buildup of vapor concentration or temperature. For safe operation, the concentration of organic vapors is usually held between 10 and 25 percent of the lower explosive limit (LEL). Newer ovens may be designed for concentrations of up to 50 percent of the LEL through the addition of monitors, alarms, and fail-safe shutdown systems. Some coatings require subsequent curing or vulcanizing in separate ovens.

Emissions sources[1-3] - The significant VOC emission sources in a polymeric coating plant include the coating preparation equipment, the coating application and flashoff area, and the drying ovens. Emissions from the solvent storage tanks and the cleanup area are normally only a small percentage of the total.

In the mixing or coating preparation area, VOC's are emitted from the individual mixers and holding tanks during the following operations: filling of mixers, transfer of the coating, intermittent activities such as changing


*
SOLVENT STORAGE
COATING PREPARATION EQUIPMENT
CONDITIONED SUBSTRATE
COATING APPLICATION/ FLASHOFF AREA
DRYING OVEN
CLEAN UP SOLVENT
CURING OVEN (OPTIONAL)
COATED SUBSTRATE

VOC emissions are denoted by an "*."

Figure 4.2.2.7-1. Solvent-borne polymetric coating operation and VOC emission locations.[1]

the filters in the holding tanks, and mixing (if mix equipment is not equipped with tightly fitting covers). The factors affecting emissions in the mixing area include tank size, number of tanks, solvent vapor pressure, throughput, and the design and performance of tank covers.

Emissions from the coating application area result from the evaporation of solvent around the coating application equipment during the application process and from the exposed substrate as it travels from the coater to the drying oven entrance (flashoff). The factors affecting emissions are the solvent content of the coating, line width and speed, coating thickness, volatility of the solvent(s), temperature, distance between coater and oven, and air turbulence in the coating area.

Emissions from the drying oven result from the fraction of the remaining solvent that is driven off in the oven. The factors affecting uncontrolled emissions are the solvent content of the coating and the amount of solvent retained in the finished product. Fugitive emissions due to the opening of oven doors also may be significant in some operations. Some plasticizers and reaction by-products may be emitted if the coating is subsequently cured or vulcanized. However, emissions from the curing or vulcanizing of the coating are usually negligible compared to the total emissions from the operation.

Solvent type and quantity are the common factors affecting emissions from all the operations in a polymeric coating facility. The rate of evaporation or drying is dependent upon solvent vapor pressure at a given temperature and concentration. The most commonly used organic solvents are toluene, dimethyl formamide (DMF), acetone, methyl ethyl ketone (MEK), isopropyl alcohol, xylene, and ethyl acetate. Factors affecting solvent selection are cost, solvency, toxicity, availability, desired rate of evaporation, ease of use after solvent recovery, and compatibility with solvent recovery equipment.

Emissions control[1,2,4-7] - A control system for evaporative emissions consists of two components: a capture device and a control device. The efficiency of the control system is determined by the efficiencies of the two components.

A capture device is used to contain emissions from a process operation and direct them to a stack or to a control device. Covers, vents, hoods, and partial and total enclosures are alternative capture devices used on coating preparation equipment. Hoods and partial and total enclosures are typical capture devices for use in the coating application area. A drying oven can be considered a capture device because it both contains and directs VOC emissions from the process. The efficiency of capture devices is variable and depends upon the quality of design and the level of operation and maintenance.

A control device is any equipment that has as its primary function the reduction of emissions. Control devices typically used in this industry are carbon adsorbers, condensers, and incinerators. Tightly fitting covers on coating preparation equipment may be considered both capture and control devices.

Carbon adsorption units use activated carbon to adsorb VOC's from a gas stream; the VOC's are later recovered from the carbon. Two types of carbon adsorbers are available: fixed bed and fluidized bed. Fixed-bed carbon adsorbers are designed with a steam-stripping technique to recover the VOC material and regenerate the activated carbon. The fluidized-bed units used in this industry are designed to use nitrogen for VOC vapor recovery and carbon regeneration. Both types achieve typical VOC control efficiencies of 95 percent when properly designed, operated, and maintained.

Condensation units control VOC emissions by cooling the solvent laden gas to the dew point of the solvent(s) and collecting the droplets. There are two condenser designs commercially available: nitrogen (inert gas) atmosphere and air atmosphere. These systems differ in the design and operation of the drying oven (i.e., use of nitrogen or air in the oven) and in the method of cooling the solvent laden air (i.e., liquified nitrogen or refrigeration). Both design types can achieve VOC control efficiencies of 95 percent.

Incinerators control VOC emissions through oxidation of the organic compounds into carbon dioxide and water. Incinerators used to control VOC emissions may be of thermal or catalytic design and may use primary or secondary heat recovery to reduce fuel costs. Thermal incinerators operate at approximately 890°C (1600°F) to assure oxidation of the organic compounds. Catalytic incinerators operate in the range of 315° to 430°C (600° to 800°F) while using a catalyst to achieve comparable oxidation of VOC's. Both design types achieve a typical VOC control efficiency of 98 percent.

Tightly fitting covers control VOC emissions from mix vessels by reducing evaporative losses. Airtight covers can be fitted with conservation vents to avoid excessive internal pressure or vacuum. The parameters affecting the efficiency of these controls are solvent vapor pressure, cyclic temperature change, tank size, throughput, and the pressure and vacuum settings on the conservation vents. A good system of tightly fitting covers on mixing area vessels is estimated to reduce emissions by approximately 40 percent. Control efficiencies of 95 or 98 percent can be obtained by directing the captured VOC's to an adsorber, condenser, or incinerator.

When the efficiencies of the capture device and control device are known, the efficiency of the control system can be computed by the following equation:

(capture efficiency)x(control efficiency)=(control system efficiency).

The terms of this equation are fractional efficiencies rather than percentages. For instance, a system of hoods delivering 60 percent of VOC emissions to a 90 percent efficient carbon adsorber would result in a control system efficiency of 54 percent (0.60x0.90=0.54). Table 4.2.2.7-1 summarizes the control system efficiencies that may be used in the absence of measured data on mix equipment and coating operations.

TABLE 4.2.2.7-1. SUMMARY OF CONTROL EFFICIENCIES[a]

Control technology	Overall control efficiency, %[b]
Coating Preparation Equipment	
Uncontrolled	0
Sealed covers with conservation vents	40
Sealed covers with carbon adsorber/condenser	95
Coating Operation[c]	
Local ventilation with carbon adsorber/condenser	81
Partial enclosure with carbon adsorber/condenser	90
Total enclosure with carbon adsorber/condenser	93
Total enclosure with incinerator	96

[a] Reference 1. To be used in the absence of measured data.

[b] To be applied to uncontrolled emissions from indicated process area, not from entire plant.

[c] Includes coating application/flashoff area and drying oven.

Emissions estimation techniques[1,4-8] - In this diverse industry, realistic estimates of emissions require solvent usage data. Due to the wide variation found in coating formulations, line speeds, and products, no meaningful inferences can be made based simply on the equipment present.

Plant-wide emissions can be estimated by performing a liquid material balance in uncontrolled plants and in those where VOC's are recovered for reuse or sale. This technique is based on the assumption that all solvent purchased replaces VOC's which have been emitted. Any identifiable and quantifiable side streams should be subtracted from this total. The general formula for this is:

$$\begin{pmatrix}\text{solvent}\\\text{purchased}\end{pmatrix}-\begin{pmatrix}\text{quantifiable}\\\text{solvent output}\end{pmatrix}=\begin{pmatrix}\text{VOC}\\\text{emitted}\end{pmatrix}.$$

The first term encompasses all solvent purchased including thinners, cleaning agents, and the solvent content of any premixed coatings as well as any solvent directly used in coating formulation. From this total, any quantifiable solvent outputs are subtracted. These outputs may include solvent retained in the finished product, reclaimed solvent sold for use outside the plant, and solvent contained in waste streams. Reclaimed solvent which is reused at the plant is not subtracted.

The advantages of this method are that it is based on data that are usually readily available, it reflects actual operations rather than theoretical steady state production and control conditions, and it includes emissions from all sources at the plant. However, care should be taken not to apply this method over too short a time span. Solvent purchases, production, and waste removal occur in their own cycles, which may not coincide exactly.

Occasionally, a liquid material balance may be possible on a smaller scale than the entire plant. Such an approach may be feasible for a single coating line or group of lines served by a dedicated mixing area and a dedicated control and recovery system. In this case, the computation begins with total solvent metered to the mixing area instead of solvent purchased. Reclaimed solvent is subtracted from this volume whether or not it is reused onsite. Of course, other solvent input and output streams must be accounted for as previously indicated. The difference between total solvent input and total solvent output is then taken to be the quantity of VOC's emitted from the equipment in question.

The configuration of meters, mixing areas, production equipment, and controls usually will not make this approach possible. In cases where control devices destroy potential emissions or a liquid material balance is inappropriate for other reasons, plant-wide emissions can be estimated by summing the emissions calculated for specific areas of the plant. Techniques for these calculations are presented below.

Estimating VOC emissions from a coating operation (application/flashoff area and drying oven) starts with the assumption that the uncontrolled emission level is equal to the quantity of solvent contained in the coating applied. In other words, all the VOC in the coating evaporates by the end of the drying process. This quantity should be adjusted downward to account for solvent retained in the finished product in cases where it is quantifiable and significant.

Two factors are necessary to calculate the quantity of solvent applied: the solvent content of the coating and the quantity of coating applied. Coating solvent content can be directly measured using EPA Reference Method 24. Alternative ways of estimating the VOC content include the use of either data on coating formulation that are usually available from the plant owner/operator or premixed coating manufacturer or, if these cannot be obtained, approximations based on the information in Table 4.2.2.7-2. The amount of coating applied may be directly metered. If it is not, it must be determined from production data. These should be available from the plant owner/operator. Care should be taken in developing these two factors to assure that they are in compatible units.

When an estimate of uncontrolled emissions is obtained, the controlled emissions level is computed by applying a control system efficiency factor:

$$\left(\begin{matrix}\text{uncontrolled}\\ \text{VOC}\end{matrix}\right) \text{x} \left(\text{1-control system efficiency}\right) = \left(\begin{matrix}\text{VOC}\\ \text{emitted}\end{matrix}\right).$$

TABLE 4.2.2.7-2. SOLVENT AND SOLIDS CONTENT OF POLYMERIC COATINGS[a]

Polymer type	Typical percentage, by weight	
	% solvent	% solids
Rubber	50-70	30-50
Urethanes	50-60	40-50
Acrylics	b	50
Vinyl[c]	60-80	20-40
Vinyl Plastisol	5	95
Organisol	15-40	60-85
Epoxies	30-40	60-70
Silicone	50-60	40-50
Nitrocellulose	70	30

[a] Reference 1.

[b] Organic solvents are generally not used in the formulation of acrylic coatings. Therefore, the solvent content for acrylic coatings represents nonorganic solvent use (i.e., water).

[c] Solvent-borne vinyl coating.

As previously explained, the control system efficiency is the product of the efficiencies of the capture device and the control device. If these values are not known, typical efficiencies for some combinations of capture and control devices are presented in Table 4.2.2.7-1. It is important to note that these control system efficiencies are applicable only to emissions that occur within the areas served by the systems. Emissions from such sources as process wastewater or discarded waste coatings may not be controlled at all.

In cases where emission estimates from the mixing area alone are desired, a slightly different approach is necessary. Here, uncontrolled emissions will be only that portion of total solvent that evaporates during the mixing process. A liquid material balance across the mixing area (i.e., solvent entering minus solvent content of coating applied) would provide a good estimate. In the absence of any measured value, it may be assumed that approximately 10 percent of the total solvent entering the mixing area is emitted during the mixing process, but this can vary widely. When an estimate of uncontrolled mixing area emissions has been made, the controlled emission rate can be calculated as discussed previously. Table 4.2.2.7-1 lists typical overall control efficiencies for coating mix preparation equipment.

Solvent storage tanks of the size typically found in this industry are regulated by only a few States and localities. Tank emissions are generally small (≤125 kg/yr). If an estimate of emissions is desired, it can be computed using the equations, tables, and figures provided in Section 4.3.2.

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4.12 POLYESTER RESIN PLASTICS PRODUCT FABRICATION

4.12.1 General Description[1-2]

A growing number of products are fabricated from liquid polyester resin reinforced with glass fibers and extended with various inorganic filler materials such as calcium carbonate, talc, mica or small glass spheres. These composite materials are often referred to as fiberglass reinforced plastic (FRP), or simply "fiberglass". The Society Of The Plastics Industry designates these materials as "reinforced plastics/composites" (RP/C). Also, advanced reinforced plastics products are now formulated with fibers other than glass, such as carbon, aramid and aramid/carbon hybrids. In some processes, resin products are fabricated without fibers. One major product using resins with fillers but no reinforcing fibers is the synthetic marble used in manufacturing bathroom countertops, sinks and related items. Other applications of nonreinforced resin plastics include automobile body filler, bowling balls and coatings.

Fiber reinforced plastics products have a wide range of application in industry, transportation, home and recreation. Industrial uses include storage tanks, skylights, electrical equipment, ducting, pipes, machine components, and corrosion resistant structural and process equipment. In transportation, automobile and aircraft applications are increasing rapidly. Home and recreational items include bathroom tubs and showers, boats (building and repair), surfboards and skis, helmets, swimming pools and hot tubs, and a variety of sporting goods.

The thermosetting polyester resins considered here are complex polymers resulting from the cross-linking reaction of a liquid unsaturated polyester with a vinyl type monomer, most often styrene. The unsaturated polyester is formed from the condensation reaction of an unsaturated dibasic acid or anhydride, a saturated dibasic acid or anhydride, and a polyfunctional alcohol. Table 4.12-1 lists the most common compounds used for each component of the polyester "backbone", as well as the principal cross-linking monomers. The chemical reactions that form both the unsaturated polyester and the cross-linked polyester resin are shown in Figure 4.12-1. The emission factors presented here apply to fabrication processes that use the finished liquid resins (as received by fabricators from chemical manufacturers), and not to the chemical processes used to produce these resins. (See Chapter 5, Chemical Process Industry.)

In order to be used in the fabrication of products, the liquid resin must be mixed with a catalyst to initiate polymerization into a solid thermoset. Catalyst concentrations generally range from 1 to 2 percent by original weight of resin; within certain limits, the higher the catalyst concentration, the faster the cross-linking reaction proceeds. Common catalysts are organic peroxides, typically methyl ethyl ketone peroxide or benzoyl peroxide. Resins may contain inhibitors, to avoid self curing during resin storage, and promoters, to allow polymerization to occur at lower temperatures.

TABLE 4.12-1. TYPICAL COMPONENTS OF RESINS

To Form the Unsaturated Polyester		
Unsaturated Acids	Saturated Acids	Polyfunctional Alcohols
Maleic anhydride	Phthalic anhydride	Propylene glycol
Fumaric acid	Isophthalic acid	Ethylene glycol
	Adipic acid	Diethylene glycol
		Dipropylene glycol
		Neopentyl glycol
		Pentaerythritol

Cross-linking Agents (Monomers)
Styrene
Methyl methacrylate
Vinyl toluene
Vinyl acetate
Diallyl phthalate
Acrylamide
2-ethyl hexylacrylate

The polyester resin/fiberglass industry consists of many small facilities (such as boat repair and small contract firms) and relatively few large firms that consume the major fraction of the total resin. Resin usage at these operations ranges from less than 5,000 kilograms per year to over 3 million kilograms per year.

Reinforced plastics products are fabricated using any of several processes, depending on their size, shape and other desired physical characteristics. The principal processes include hand layup, spray layup (sprayup), continuous lamination, pultrusion, filament winding and various closed molding operations.

Hand layup, using primarily manual techniques combined with open molds, is the simplest of the fabrication processes. Here, the reinforcement is manually fitted to a mold wetted with catalyzed resin mix, after which it is saturated with more resin. The reinforcement is in the form of either a chopped strand mat, a woven fabric or often both. Layers of reinforcement and resin are added to build the desired laminate thickness. Squeegees, brushes and rollers are used to smooth and compact each layer as it is applied. A release agent is usually first applied to the mold to facilitate removal of the composite. This is often a wax, which can be treated with a water soluble barrier coat such as polyvinyl alcohol to promote paint adhesion on parts that are to be painted. In many operations,

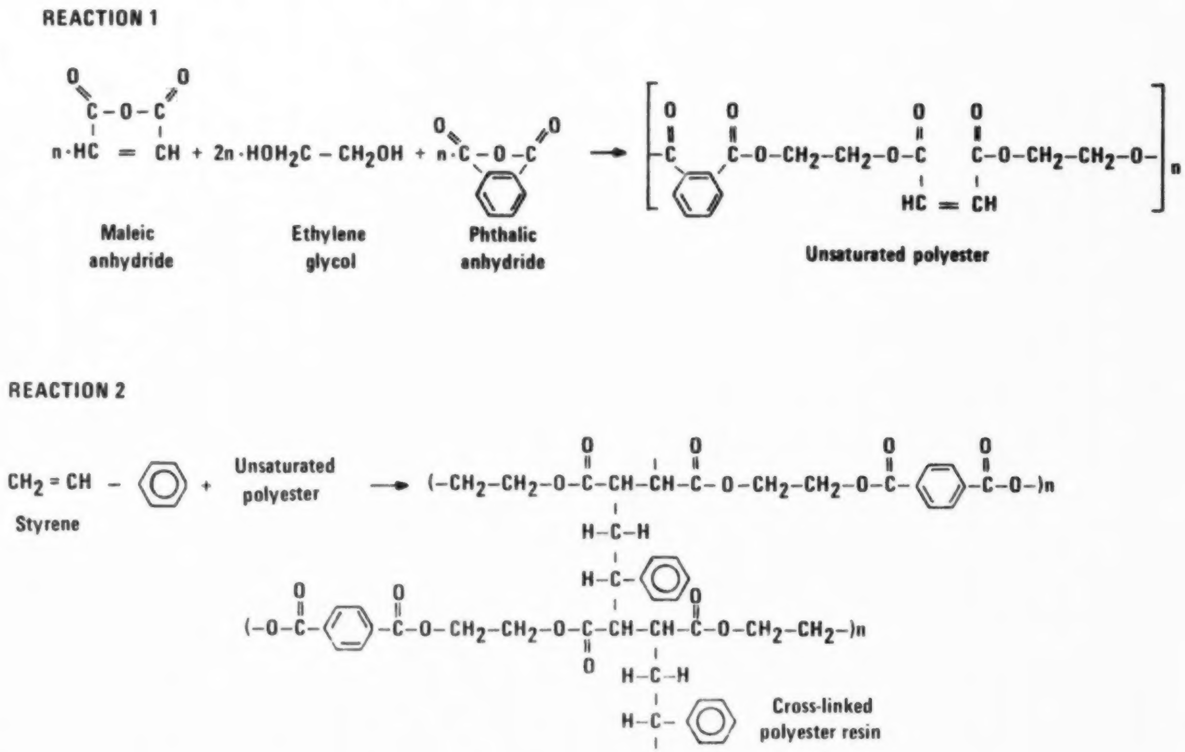
REACTION 1
Maleic anhydride
Ethylene glycol
Phthalic anhydride
Unsaturated polyester
REACTION 2
Styrene
Unsaturated polyester
Cross-linked polyester resin

Figure 4.12-1. Typical reactions for unsaturated polyester and polyester resin formation.

the mold is first sprayed with gel coat, a clear or pigmented resin mix that forms the smooth outer surface of many products. Gel coat spray systems consist of separate sources of resin and catalyst, with an airless hand spray gun that mixes them together into an atomized resin/catalyst stream. Typical products are boat hulls and decks, swimming pools, bathtubs and showers, electrical consoles and automobile components.

Spray layup, or "sprayup", is another open mold process, differing from hand layup in that it uses mechanical spraying and chopping equipment for depositing the resin and glass reinforcement. This process allows a greater production rate and more uniform parts than does hand layup, and often uses more complex molds. As in hand layup, gel coat is frequently applied to the mold before fabrication to produce the desired surface qualities. It is common practice to combine hand layup and sprayup operations.

For the reinforced layers, a device is attached to the sprayer system to chop glass fiber "roving" (uncut fiber) into predetermined lengths and project it to merge with the resin mix stream. The stream precoats the chop, and both are deposited simultaneously to the desired layer thickness on the mold surface (or on the gel coat that was applied to the mold). Layers are built up and rolled out on the mold as necessary to form the part. Products manufactured by sprayup are similar to those made by hand layup, except that more uniform and complex parts can generally be produced more efficiently with sprayup techniques. However, compared to hand layup, more resin generally is used to produce similar parts by spray layup because of the inevitable overspray of resin during application.

Continuous lamination of reinforced plastics materials involves impregnating various reinforcements with resins on an in-line conveyor. The resulting laminate is cured and trimmed as it passes through the various conveyor zones. In this process, the resin mix is metered onto a bottom carrier film, using a blade to control thickness. This film, which defines the panel's surface, is generally polyester, cellophane or nylon, and may have a smooth, embossed or matte surface. Methyl methacrylate is sometimes used as the cross-linking agent, either alone or in combination with styrene, to increase strength and weather resistance. Chopped glass fibers free-fall into the resin mix and are allowed to saturate with resin, or "wet out". A second carrier film is applied on top of the panel before subsequent forming and curing. The cured panel is then stripped of its films, trimmed and cut to the desired length. Principal products include translucent industrial skylights and greenhouse panels, wall and ceiling liners for food areas, garage doors and cooling tower louvers. Figure 4.12-2 shows the basic elements of a continuous laminating production line.

Pultrusion, which can be thought of as extrusion by pulling, is used to produce continuous cross-sectional lineals similar to those made by extruding metals such as aluminum. Reinforcing fibers are pulled through a liquid resin mix bath and into a long machined steel die, where heat initiates an exothermic reaction to polymerize the thermosetting resin matrix. The composite profile emerges from the die as a hot, constant cross-sectional that cools sufficiently to be fed into a clamping and pulling mechanism. The product can then be cut to desired lengths. Example products include electrical insulation materials, ladders, walkway gratings, structural supports, and rods and antennas.

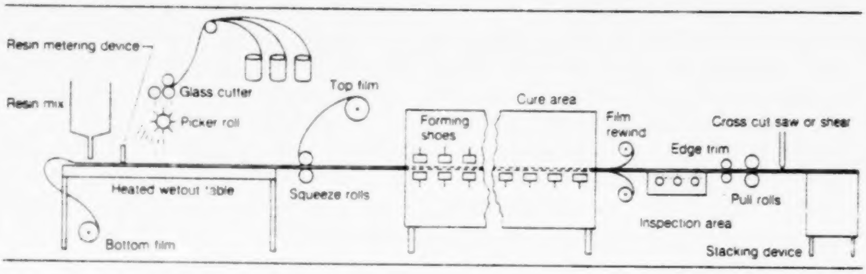
Resin metering device
Resin mix
Glass cutter
Picker roll
Top film
Cure area
Forming shoes
Film rewind
Cross cut saw or shear
Edge trim
Heated wetout table
Squeeze rolls
Pull rolls
Inspection area
Bottom film
Stacking device

Figure 4.12-2. Typical continuous lamination production process.[2]

Filament winding is the process of laying a band of resin impregnated fibers onto a rotating mandrel surface in a precise geometric pattern, and curing them to form the product. This is an efficient method of producing cylindrical parts with optimum strength characteristics suited to the specific design and application. Glass fiber is most often used for the filament, but aramid, graphite, and sometimes boron and various metal wires may be used. The filament can be wetted during fabrication, or previously impregnated filament ("prepreg") can be used. Figure 4.12-3 shows the filament winding process, and indicates the three most common winding patterns. The process illustration depicts circumferential winding, while the two smaller pictures show helical and polar winding. The various winding patterns can be used alone or in combination to achieve the desired strength and shape characteristics. Mandrels are made of a wide variety of materials and, in some applications, remain inside the finished product as a liner or core. Example products are storage tanks, fuselages, wind turbine and helicopter blades, and tubing and pipe.

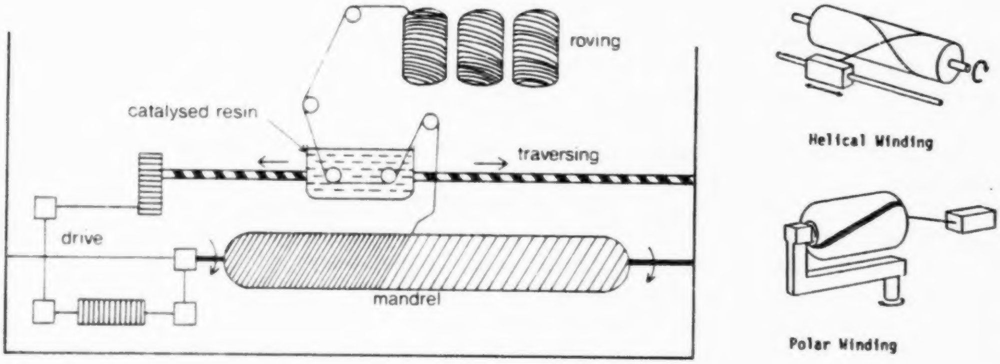
roving
catalysed resin
traversing
drive
mandrel
Helical Winding
Polar Winding

Figure 4.12-3. Typical filament winding process.[3]

Closed, such as compression or injection, molding operations involve the use of two matched dies to define the entire outer surface of the part. When closed and filled with a resin mix, the matched die mold is subjected to heat and pressure to cure the plastic. For the most durable production configuration, hardened metal dies are used (matched metal molding). Another closed molding process is vacuum or pressure bag molding. In bag molding, a hand layup or sprayup is covered with a plastic film, and vacuum or pressure is applied to rigidly define the part and improve surface quality. The range of closed molded parts includes tool and appliance housings, cookware, brackets and other small parts, and automobile body and electrical components.

Synthetic marble casting, a large segment of the resin products industry, involves production of bathroom sinks, vanity tops, bathtubs and accessories using filled resins that have the look of natural marble. No reinforcing fibers are used in these products. Pigmented or clear gel coat can either be applied to the mold itself or sprayed onto the product after casting to simulate the look of natural polished marble. Marble casting can be an open mold process, or it may be considered a semiclosed process if cast parts are removed from a closed mold for subsequent gel coat spraying.

4.12.2 Emissions And Controls

Organic vapors consisting of volatile organic compounds (VOC) are emitted from fresh resin surfaces during the fabrication process and from the use of solvents (usually acetone) for cleanup of hands, tools, molds and spraying equipment. Cleaning solvent emissions can account for over 36 percent of the total plant VOC emissions.[4] There also may be some release of particulate emissions from automatic fiber chopping equipment, but these emissions have not been quantified.

Organic vapor emissions from polyester resin/fiberglass fabrication processes occur when the cross-linking agent (monomer) contained in the liquid resin evaporates into the air during resin application and curing. Styrene, methyl methacrylate and vinyl toluene are three of the principal monomers used as cross-linking agents. Styrene is by far the most common. Other chemical components of resins are emitted only at trace levels, because they not only have low vapor pressures but also are substantially converted to polymers.[5-6]

Since emissions result from evaporation of monomer from the uncured resin, they depend upon the amount of resin surface exposed to the air and the time of exposure. Thus, the potential for emissions varies with the manner in which the resin is mixed, applied, handled and cured. These factors vary among the different fabrication processes. For example, the spray layup process has the highest potential for VOC emissions because the atomization of resin into a spray creates an extremely large surface area from which volatile monomer can evaporate. By contrast, the emission potential in synthetic marble casting and closed molding operations is considerably lower, because of the lower monomer content in the casting resins (30 to 38 percent, versus about 43 percent) and of the enclosed nature of these molding operations. It has been found that styrene evaporation increases with increasing gel time, wind speed and ambient temperature, and that increasing the hand rolling time on a hand layup or sprayup results in significantly higher styrene losses.[1] Thus, production changes that lessen the exposure of fresh resin surfaces to the air should be effective in reducing these evaporation losses.

In addition to production changes, resin formulation can be varied to affect the VOC emission potential. In general, a resin with lower monomer content should produce lower emissions. Evaluation tests with low-styrene-emission laminating resins having a 36 percent styrene content found a 60 to 70 percent decrease in emission levels, compared to conventional resins (42 percent styrene), with no sacrifice in the physical properties of the laminate.[7] Vapor suppressing agents also are sometimes added to resins to reduce VOC emissions. Most vapor suppressants are paraffin waxes, stearates or polymers of proprietary composition, constituting up to several weight percent of the mix. Limited laboratory and field data indicate that vapor suppressing resins reduce styrene losses by 30 to 70 percent.[7-8]

Emission factors for several fabrication processes using styrene content resins have been developed from the results of facility source tests (B Rating) and laboratory tests (C Rating), and through technology transfer estimations (D Rating).[1] Industry experts also provided additional information that was used to arrive at the final factors presented in Table 4.12-2.[6] Since the styrene content varies over a range of approximately 30 to 50 weight percent, these factors are based on the quantity of styrene monomer used in the process, rather than on the total amount of resin used. The factors for vapor-suppressed resins are typically 30 to 70 percent of those for regular resins. The factors are expressed as ranges, because of the observed variability in source and laboratory test results and of the apparent sensitivity of emissions to process parameters.

Emissions should be calculated using actual resin monomer contents. When specific information about the percentage of styrene is unavailable, the representative average values in Table 4.12-3 should be used. The sample calculation illustrates the application of the emission factors.

> Sample Calculation - A fiberglass boat building facility consumes an average of 250 kg per day of styrene-containing resins using a combination of hand layup (75%) and spray layup (25%) techniques. The laminating resins for hand and spray layup contain 41.0 and 42.5 weight percent, respectively, of styrene. The resin used for hand layup contains a vapor-suppressing agent.
>
> From Table 4.12-2, the factor for hand layup using a vapor-suppresed resin is 2 - 7 (0.02 to 0.07 fraction of total styrene emitted); the factor for spray layup is 9 - 13 (0.09 to 0.13 fraction emitted). Assume the midpoints of these emission factor ranges.
>
> Total VOC emissions are:

$$(250\ \text{kg/day})\ [(0.41)(0.045)(0.75) + (0.425)(0.11)(0.25)]$$

$$= 6.4\ \text{kg/day.}$$

TABLE 4.12-2. EMISSION FACTORS FOR UNCONTROLLED POLYESTER RESIN PRODUCT FABRICATION PROCESSES[a]

(100 x mass of VOC emitted/mass of monomer input)

Process	Resin		Emission Factor Rating	Gel Coat		Emission Factor Rating
	NVS	VS[b]		NVS	VS[b]	
Hand layup	5 - 10	2 - 7	C	26 - 35	8 - 25	D
Spray layup	9 - 13	3 - 9	B	26 - 35	8 - 25	B
Continuous lamination	4 - 7	1 - 5	B	c	c	--
Pultrusion[d]	4 - 7	1 - 5	D	c	c	--
Filament winding[e]	5 - 10	2 - 7	D	c	c	--
Marble casting	1 - 3	1 - 2	B	f	f	--
Closed molding[g]	1 - 3	1 - 2	D	c	c	--

[a] Reference 9. Ranges represent the variability of processes and sensitivity of emissions to process parameters. Single value factors should be selected with caution. NVS = nonvapor-suppressed resin. VS = vapor-suppressed resin.

[b] Factors are 30-70% of those for nonvapor-suppressed resins.

[c] Gel coat is not normally used in this process.

[d] Resin factors for the continuous lamination process are assumed to apply.

[e] Resin factors for the hand layup process are assumed to apply.

[f] Factors unavailable. However, when cast parts are subsequently sprayed with gel coat, hand and spray layup gel coat factors are assumed to apply.

[g] Resin factors for marble casting, a semiclosed process, are assumed to apply.

TABLE 4.12-3. TYPICAL RESIN STYRENE PERCENTAGES

Resin Application	Resin Styrene Content[a] (wgt. %)
Hand layup	43
Spray layup	43
Continuous lamination	40
Filament winding	40
Marble casting	32
Closed molding	35
Gel coat	35

[a] May vary by at least ±5 percentage points.

Emissions from use of gel coat would be calculated in the same manner. If the monomer content of the resins were unknown, a representative value of 43 percent could be selected from Table 4.12-3 for this process combination. It should be noted that these emissions represent evaporation of styrene monomer only, and not of acetone or other solvents used for cleanup.

In addition to process changes and materials substitution, add-on control equipment can be used to reduce vapor emissions from styrene resins. However, control equipment is infrequently used at RP/C fabrication facilities, due to low exhaust VOC concentrations and the potential for contamination of adsorbent materials. Most plants use forced ventilation techniques to reduce worker exposure to styrene vapors, but vent the vapors directly to the atmosphere with no attempt at collection. At one continuous lamination facility where incineration was applied to vapors vented from the impregnation table, a 98.6 percent control efficiency was measured.[1] Carbon adsorption, absorption and condensation also have been considered for recovering styrene and other organic vapors, but these techniques have not been applied to any significant extent in this industry.

Emissions from cleanup solvents can be controlled through good housekeeping and use practices, reclamation of spent solvent, and substitution with water based solvent substitutes.

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5.15 SOAP AND DETERGENTS

5.15.1 Soap Manufacture

Process Description[2] - Soap may be manufactured by either batch or continuous process, using either the alkaline saponification of natural fats and oils or the direct saponification of fatty acids. The kettle, or full boiled, method is a batch process of several steps, in either a single kettle or a series of kettles. Fats and oils are saponified by live steam boiling in a caustic solution, followed by "graining", which is precipitating the soft curds of soap out of the aqueous lye solution by adding sodium chloride (salt). The soap solution then is washed to remove glycerine and color body impurities, to leave the "neat" soap to form during a settling period. Continuous alkaline saponification of natural fats and oils follows the same steps as batch processing, but it eliminates the need for a lengthy process time. Direct saponification of fatty acids is also accomplished in continuous processes. Fatty acids obtained by continuous hydrolysis usually are continuously neutralized with caustic soda in a high speed mixer/neutralizer to form soap.

All soap is finished for consumer use in such varied forms as liquid, powder, granule, chip, flake or bar.

Emissions And Controls[2] - The main atmospheric pollution problem in the manufacture of soap is odor. Vent lines, vacuum exhausts, product and raw material storage, and waste streams are all potential odor sources. Control of these odors may be achieved by scrubbing all exhaust fumes and, if necessary, incinerating the remaining compounds. Odors emanating from the spray dryer may be controlled by scrubbing with an acid solution.

Blending, mixing, drying, packaging and other physical operations all may involve dust emissions. The production of soap powder by spray drying is the largest single source of dust in the manufacture of soap. Dust emissions from other finishing operations can be controlled by dry filters such as baghouses. The large sizes of the particulate from soap drying mean that high efficiency cyclones installed in series can give satisfactory control.

5.15.2 Detergent Manufacture

Process Description[1-3] - The manufacture of spray dried detergent has three main processing steps, slurry preparation, spray drying and granule handling. Figure 5.15-1 illustrates the various operations. Detergent slurry is produced by blending liquid surfactant with powdered and liquid materials (builders and other additives) in a closed mixing tank called a crutcher. Liquid surfactant used in making the detergent slurry is produced by the sulfonation, or sulfation by sulfuric acid, of either a linear alkylate or a fatty acid, which is then neutralized with caustic solution (NaOH). The blended slurry is held in a surge vessel for continuous pumping to a spray dryer. The slurry is sprayed at high pressure into a vertical drying tower having a stream of hot air of from 315° to 400°C (600° to 750°F). Most towers designed for detergent production are countercurrent, with slurry introduced at the top and heated air introduced at the bottom. The detergent granules thus formed are conveyed mechanically or by air from the tower to a mixer, to incorporate additional dry or liquid ingredients, and finally to packaging and storage.

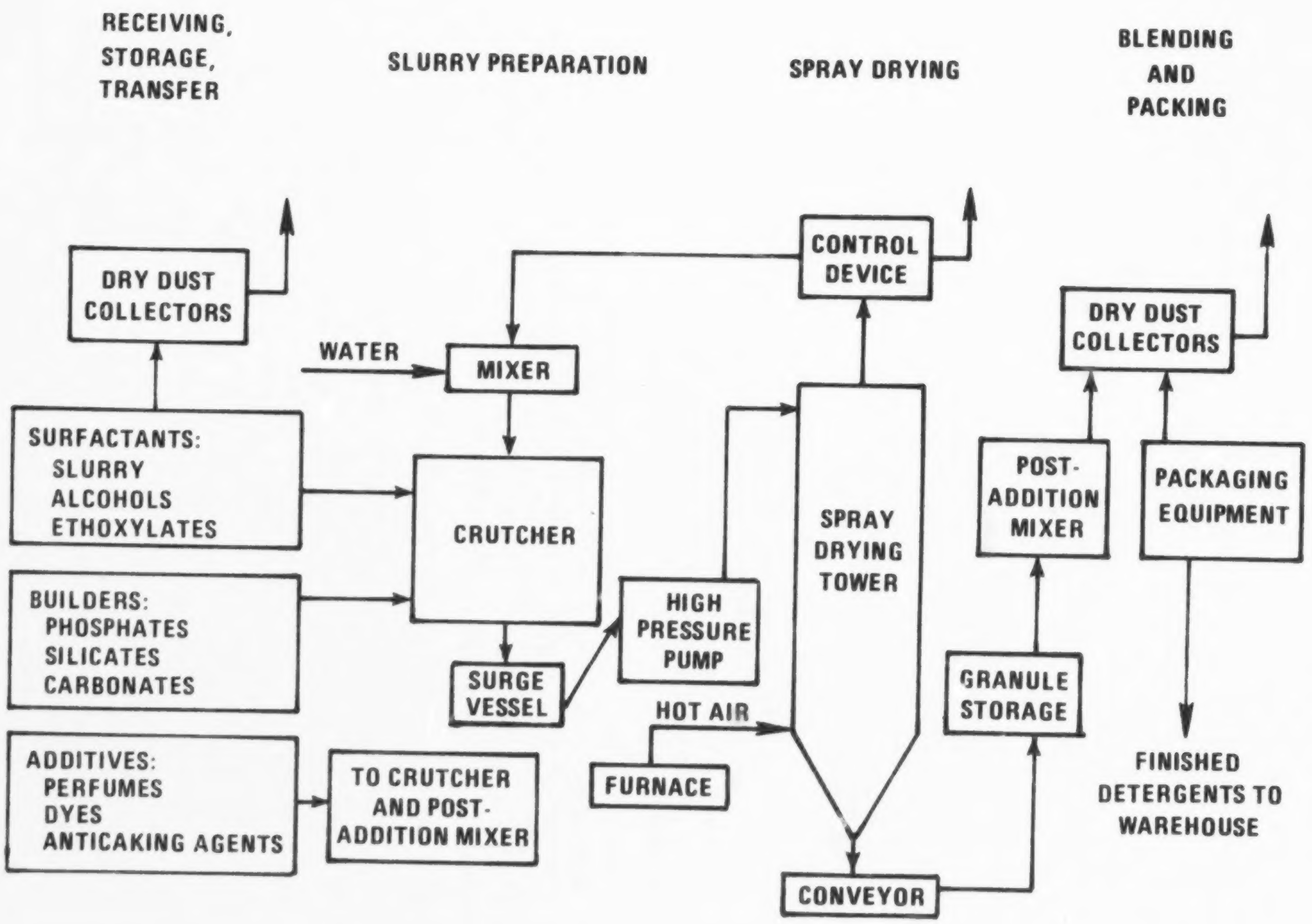
RECEIVING, STORAGE, TRANSFER
SLURRY PREPARATION
SPRAY DRYING
BLENDING AND PACKING
DRY DUST COLLECTORS
CONTROL DEVICE
DRY DUST COLLECTORS
WATER
MIXER
SURFACTANTS: SLURRY ALCOHOLS ETHOXYLATES
CRUTCHER
SPRAY DRYING TOWER
POST-ADDITION MIXER
PACKAGING EQUIPMENT
BUILDERS: PHOSPHATES SILICATES CARBONATES
HIGH PRESSURE PUMP
SURGE VESSEL
HOT AIR
GRANULE STORAGE
ADDITIVES: PERFUMES DYES ANTICAKING AGENTS
TO CRUTCHER AND POST-ADDITION MIXER
FURNACE
CONVEYOR
FINISHED DETERGENTS TO WAREHOUSE

Figure 5.15-1. Manufacture of spray dried detergents.

Emissions And Controls$^{2-3}$ - In the batching and mixing of fine dry ingredients to form slurry, dust emissions are generated at scale hoppers, mixers and crutchers. Fabric filters are used, not only to reduce or to eliminate the dust emissions but also to recover raw materials. Emission factors for particulate from spray drying operations are shown in Table 5.15-1. Table 5.15-2 and Figure 5.15-2 give size specific particulate emission factors for operations on which information is available. There is also a minor source of volatile organics when the product being sprayed contains organic materials with low vapor pressures. These vaporized organic materials condense in the tower exhaust air stream into droplets or particles.

Dry cyclones and cyclonic impingement scrubbers are the primary collection equipment employed to capture the detergent dust in the spray dryer exhaust for return to process. Dry cyclones are used, in parallel or in series, to collect particulate (detergent dust) and to recycle it back to the crutcher. Cyclonic impinged scrubbers are used, in parallel, to collect the particulate from a scrubbing slurry and to recycle it to the crutcher. Secondary collection equipment is used to collect the fine particulate that has escaped from the primary devices. Cyclonic impingement scrubbers are often followed by mist eliminators, and dry cyclones are followed by fabric filters or scrubber/electrostatic precipitator units. Conveying, mixing and packaging of detergent granules can cause dust emissions. Usually, fabric filters provide the best control.

TABLE 5.15-1. PARTICULATE EMISSION FACTORS FOR DETERGENT SPRAY DRYING[a]

EMISSION FACTOR RATING: B

		Particulate	
Control device	Efficiency (%)	kg/Mg of product	lb/ton of product
Uncontrolled	-	45	90
Cyclone[b]	85	7	14
Cyclone			
w/Spray chamber	92	3.5	7
w/Packed scrubber	95	2.5	
w/Venturi scrubber	97	1.5	
w/Wet scrubber	99	0.544	1.08
w/Wet scrubber/ESP	99.9	0.023	0.046
Fabric filter	99	0.54	1.1

[a] References 4-8. VOC emissions data have not been reported in the literature. Dash = not applicable. ESP = electrostatic precipitator.

[b] Some type of primary collector, such as a cyclone, is considered integral to a spray drying system.

TABLE 5.15-2. PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR DETERGENT SPRAY DRYING[a]

EMISSION FACTOR RATING: D

Control device	Particle size distribution[b] (Cum. wt. %)			Particulate emission factor[c] (kg/Mg)		
	≤2.5 um	≤6.0 um	≤10.0 um	≤2.5 um	≤6.0 um	≤10.0 um
Uncontrolled	50.2	60.4	66.1	23	27	30
Fabric filter	61.9	76.5	81.8	0.33	0.41	0.44
Cyclone	74.5	90.8	95.8	5.2	6.4	6.7
Cyclone and wet scrubber	86.5	100	100	0.470	0.544	0.544
Cyclone and wet scrubber/ electrostatic precipitator	97.0	97.7	99.9	0.023	0.023	0.023

[a] References 9-14. Particle size refers to aerodynamic particle diameter.
[b] Cumulative weight % of particles ≤ corresponding particle size.
[c] Equals total particulate emission factor (Table 5.15-1) x particle size distribution (%)/100. Expressed as units/unit weight of product.

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6.4 GRAIN ELEVATORS AND PROCESSING PLANTS

6.4.1 General[1-3]

Grain elevators are facilities at which grains are received, stored, and then distributed for direct use, process manufacturing, or export. They can be classified as either "country" or "terminal" elevators, with terminal elevators further categorized as inland or export (marine) types. Operations other than storage often are performed at elevators, such as cleaning, drying and blending. The principal grains handled include wheat, milo, corn, oats, rice and soybeans.

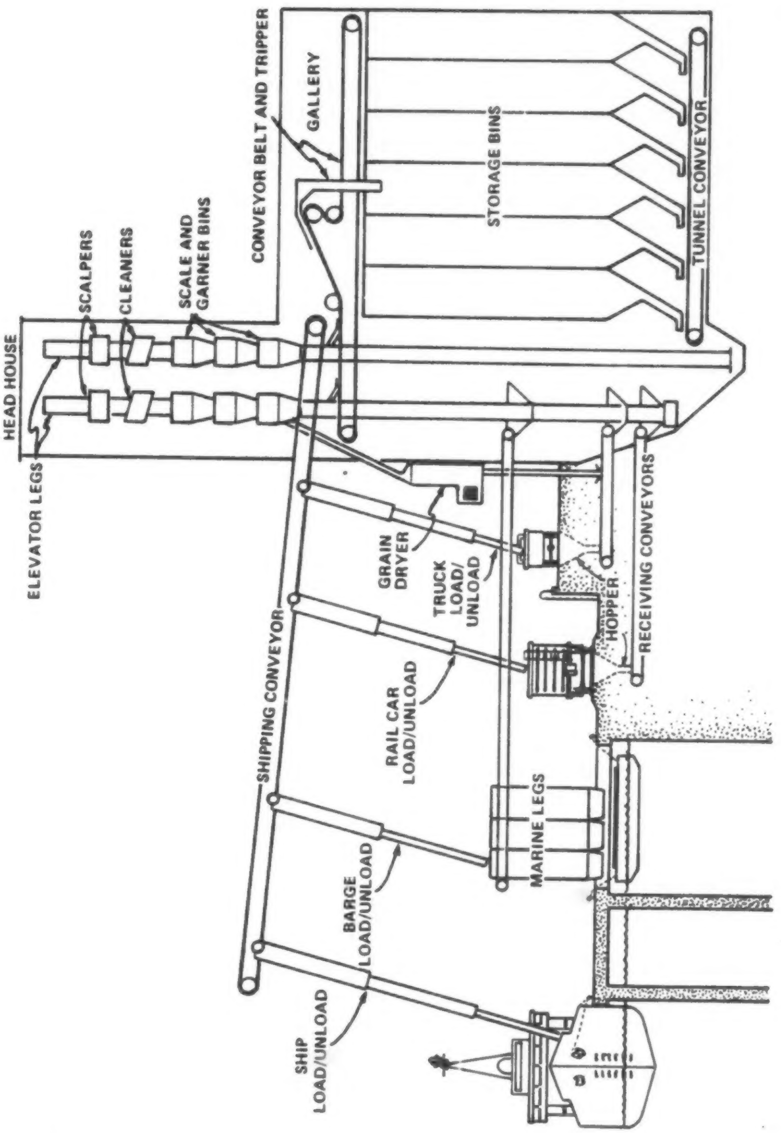
Country elevators are generally smaller elevators that receive grain by truck directly from farms during the harvest season. These elevators sometimes clean or dry grain before it is transported to terminal elevators or processors. Terminal elevators dry, clean, blend and store grain for shipment to other terminals or processors, or for export. These elevators may receive grain by truck, rail or barge, and they have significantly greater grain handling and storage capacities than do country elevators. Export elevators are terminal elevators that load grain primarily onto ships for export.

The first step at a grain elevator is the unloading of the incoming truck, railcar or barge. A truck discharges its grain into a hopper, usually below grade, from which the grain is conveyed to the main part of the elevator. Barges are unloaded by a bucket elevator (marine leg) that is extended down into the hold. The main building at an elevator, where grain is elevated and distributed, is called the "headhouse". In the headhouse, grain is lifted on one of the elevator legs and discharged onto the gallery belt, which conveys the grain to the storage bins, or silos. A "tripper" diverts grain into the desired bin. Grain is often cleaned and/or dried before storage. When ready for shipping, grain is discharged from bins onto the tunnel belt below, which conveys it to the scale garner and on to the desired loadout location. Figure 6.4-1 illustrates the basic elements of an export terminal elevator.

A grain processing plant (mill) receives grain from an elevator and performs various manufacturing steps that produce a finished food product. Examples of these plants are flour mills, animal feed mills, and producers of edible oils, starch, corn syrup, and cereal products. The elevator operations of unloading, conveying and storing also are performed at mills.

6.4.2 Emissions And Controls[1]

The only pollutant emitted in significant quantities from grain elevators and processing operations is particulate matter. Small amounts of combustion products from natural gas fired grain dryers also may be emitted. Grain elevators and grain processing operations can be considered separate categories of the industry when considering emissions.



HEAD HOUSE
ELEVATOR LEGS
SCALPERS
CLEANERS
SCALE AND GARNER BINS
CONVEYOR BELT AND TRIPPER
GALLERY
STORAGE BINS
TUNNEL CONVEYOR
GRAIN DRYER
TRUCK LOAD/ UNLOAD
HOPPER
RECEIVING CONVEYORS
SHIPPING CONVEYOR
RAIL CAR LOAD/UNLOAD
MARINE LEGS
BARGE LOAD/UNLOAD
SHIP LOAD/UNLOAD

Figure 6.4-1. Typical export terminal grain elevator.

6.4.2.1 Grain Elevators - Emissions of fugitive dust occur whenever quantities of grain are set into motion during loading, conveying, transfer, drying or cleaning operations at a grain elevator. The emission rate can be affected by the quantity of foreign material in the grain (dirt, seeds, sticks, stones, etc., known as "dockage") and by the type of grain. While it is difficult to quantify the effect of dockage, observations indicate that soybeans, oats and sorghum are usually very dusty, whereas wheat and corn are comparatively clean.[4] Total particulate emission factors for the principal operations at grain elevators are presented in Table 6.4-1. Since data differentiating these emission factors by grain type are sparse, all of these factors are approximate average values intended to apply to a variety of grains. Tables 6.4-2, 6.4-3 and 6.4-4, and Figures 6.4-2, 6.4-3 and 6.4-4, show particle size distributions and size specific emission factors for three operations at grain elevators.

The emission factors in Table 6.4-1 represent the amount of dust generated per unit weight of grain processed through each uncontrolled operation. Since the amount of grain passing through each individual operation is often difficult to determine, it is sometimes convenient to express the emission factors in terms of the quantity of grain received or shipped by the elevator. (It is assumed that the amounts shipped and received are equal over the long run.) Therefore, the factors in Table 6.4-1 have been modified and are expressed in Table 6.4-5 as a function of the amount of grain received or shipped. The ratios shown in Table 6.4-5 are approximate values based on averages for bin turning, cleaning and drying in each elevator category. However, because operating practices at individual elevators are different, these ratios, like the emission factors themselves, may lack precision when applied to an individual elevator.

The factors in Tables 6.4-1 and 6.4-5 should not be added together in order to obtain a single overall emission factor for a grain elevator because, in most elevators, the emissions from some operations are controlled and others are not. Therefore, emissions estimations generally should be undertaken for each operation and its associated control device.

Several methods are available to reduce or control dust emissions at grain elevators. Since most emissions are generated when air passes swiftly through a mass of grain, measures that slow down grain transfer (conveying) rates or that reduce free fall distances will reduce emissions. Bulk grain, especially when falling through the air, should be protected from significant air currents or wind sources. Many operations at elevators are partially or totally enclosed (e. g., screw conveyors, drag conveyors, elevator legs) to isolate generated dust from the atmosphere. Hooding in the vicinity of some operations (e. g., grain unloading, conveyor transfer points) collects generated dust by creating a negative pressure area (through suction, or air aspiration) near the center of activity and then ducting the dusty air to a control device. Recent developments in the control of ship and barge loading operations include the use of "dead boxes" and tent controls. The dead box is a baffled attachment on the loading spout that serves to reduce the speed of the falling grain before it reaches the open air and strikes the grain pile. Aspiration to a control device often accompanies the use of the dead box. Large flexible covers connected to the loading spout and aspiration ducting, called tents, are used to cover the holds of ships during most of a loading operation. The tent must be removed during topping off (usually

TABLE 6.4-1. TOTAL PARTICULATE EMISSION FACTORS FOR UNCONTROLLED GRAIN ELEVATORS[a]

EMISSION FACTOR RATING: B

Type of Operation	Total particulate	
	kg/Mg	lb/ton
Country elevators		
Unloading (receiving)	0.3	0.6
Loading (shipping)	0.2	0.3
Removal from bins (tunnel belt)	0.5	1.0
Drying[b]	0.4	0.7
Cleaning[c]	1.5	3.0
Headhouse (legs)	0.8	1.5
Inland terminal elevators		
Unloading (receiving)	0.5	1.0
Loading (shipping)	0.2	0.3
Removal from bins (tunnel belt)	0.7	1.4
Drying[b]	0.6	1.1
Cleaning[c]	1.5	3.0
Headhouse (legs)	0.8	1.5
Tripper (gallery belt)	0.5	1.0
Export elevators		
Unloading (receiving)	0.5	1.0
Loading (shipping)	0.5	1.0
Removal from bins (tunnel belt)	0.7	1.4
Drying[b]	0.5	1.1
Cleaning[c]	1.5	3.0
Headhouse (legs)	0.8	1.5
Tripper (gallery belt)	0.5	1.0

[a] Expressed as weight of dust emitted/unit weight of grain handled by each operation. For inland terminal and export elevators, Reference 5; for drying, References 2, 6; for country elevators, Reference 5 and additional test data in References 7-10.

[b] References 6, 11. Based on 0.9 kg/Mg for uncontrolled rack dryers and 0.15 kg/Mg for uncontrolled column dryers, prorated on the basis of the distribution of these two types of dryers.

[c] Reference 11. Average of values, from < 0.3 kg/Mg for wheat to 3.0 kg/Mg for corn.

TABLE 6.4-2. PARTICLE SIZE DISTRIBUTION AND EMISSION FACTORS FOR UNCONTROLLED RICE DRYERS[a]

EMISSION FACTOR RATING: D

Aerodynamic particle diameter (um)	Cumulative weight % ≤ stated size	Emission factor[b] (kg/Mg)
2.5	0.8	0.0012
6.0	2.6	0.0039
10.0	7.7	0.012
15.0	24.5	0.037
Total particulate		0.15[c]

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[a] References 1, 12.

[b] Expressed as cumulative weight of particulate ≤ corresponding particle size/unit weight of rice dried.

[c] Reference 11.

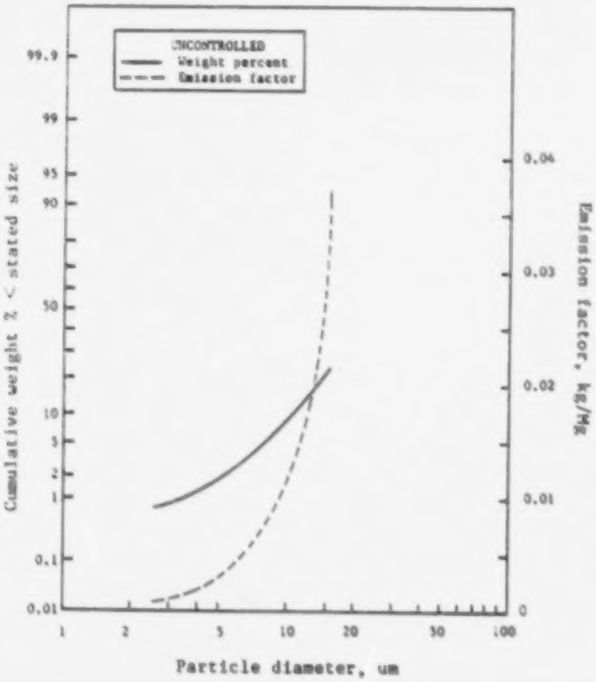

Figure 6.4-2. Cumulative size distribution and emission factors for uncontrolled rice dryers.

TABLE 6.4-3. PARTICLE SIZE DISTRIBUTION AND EMISSION FACTORS FOR CONTROLLED BARGE UNLOADING/CONVEYING[a]

EMISSION FACTOR RATING: D

Aerodynamic particle diameter (um)	Cumulative weight % ≤ stated size	Emission factor[b] (kg/Mg)
2.5	4.0	0.00013
6.0	11.0	0.00037
10.0	18.0	0.00054
Total particulate		0.003[c]

[a] Reference 13. Control is by fabric filter.

[b] Expressed as cumulative weight of particulate ≤ corresponding particle size/unit weight of grain unloaded/conveyed.

[c] Total mass emission factor is from Reference 1.

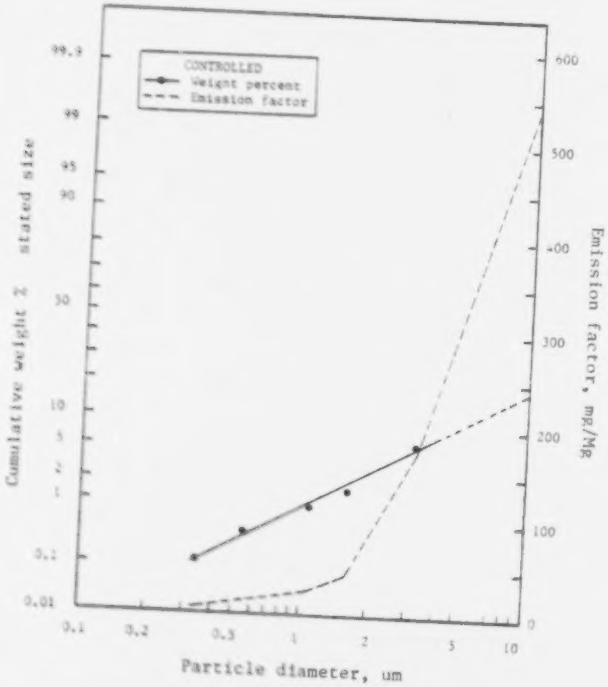

Figure 6.4-3. Cumulative size distribution and emission factors for controlled barge unloading/conveying.

TABLE 6.4-4. PARTICLE SIZE DISTRIBUTION AND EMISSION FACTORS FOR UNCONTROLLED SHIPLOADING[a]

EMISSION FACTOR RATING: C

Aerodynamic particle diameter (um)	Cumulative weight % ≤ stated size	Emission factor[b] (kg/Mg)
2.5	10.4	0.05
6.0	27.0	0.13
10.0	42.0	0.21
15.0	53.0	0.26
Total particulate		0.50[c]

[a] References 1, 14-15.

[b] Expressed as cumulative weight of particulate ≤ corresponding particle size/unit weight of grain loaded onto ships.

[c] Reference 11.

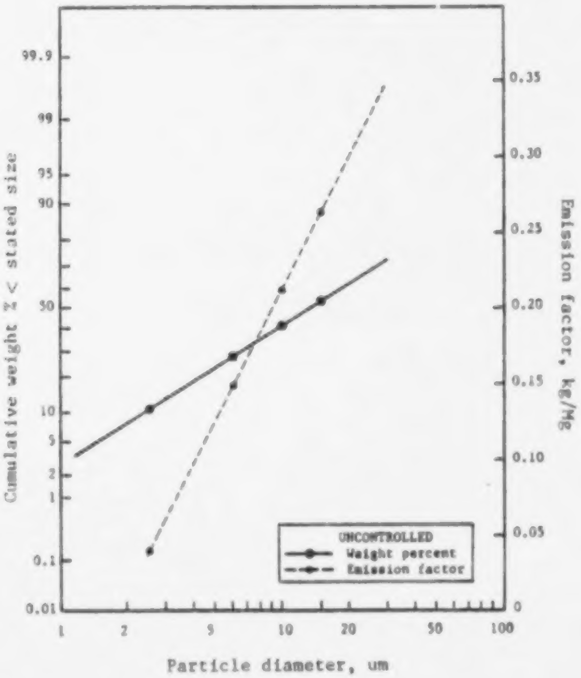

Figure 6.4-4. Cumulative size distribution and emission factors for uncontrolled shiploading.

TABLE 6.4-5. TOTAL PARTICULATE EMISSION FACTORS FOR GRAIN ELEVATORS, BASED ON AMOUNT OF GRAIN RECEIVED OR SHIPPED[a]

EMISSION FACTOR RATING: C

Type of Operation	Emission factor, kg/Mg handled[b]	x	Typical ratio of grain processed to grain received or shipped[c]	=	Emission factor, kg/Mg received or shipped
Country elevators					
Unloading (receiving)	0.3		1.0		0.3
Loading (shipping)	0.2		1.0		0.2
Removal from bins (tunnel belt)	0.5		2.1		1.0
Drying[d]	0.4		0.3		0.1
Cleaning[e]	1.5		0.1		0.2
Headhouse (legs)	0.8		3.1		2.5
Inland terminal elevators					
Unloading (receiving)	0.5		1.0		0.5
Loading (shipping)	0.2		1.0		0.2
Removal from bins (tunnel belt)	0.7		2.0		1.4
Drying[d]	0.6		0.1		0.1
Cleaning[e]	1.5		0.2		0.3
Headhouse (legs)	0.8		3.0		2.3
Tripper (gallery belt)	0.5		1.7		0.8
Export elevators					
Unloading (receiving)	0.5		1.0		0.5
Loading (shipping)	0.5		1.0		0.5
Removal from bins (tunnel belt)	0.7		1.2		0.8
Drying[d]	0.5		0.01		0.01
Cleaning[e]	1.5		0.2		0.3
Headhouse (legs)	0.8		2.2		1.7
Tripper (gallery belt)	0.5		1.1		0.6

[a] Assumes amount received is approximately equal to the amount shipped.

[b] To obtain units of lb/ton, multiply factors by 2.0.

[c] Reference 6. Average values from a survey of elevators across the U. S. Can be considerably different for any individual elevator or group of elevators in the same locale.

[d] See Note b in Table 6.4-1.

[e] See Note c in Table 6.4-1.

about 25 percent of the total loading), allowing essentially uncontrolled emissions to escape.

Most elevators utilize particulate control devices on at least some of their operations. The traditional form of control at elevators has been mechanical collectors, or cyclones. Cyclones collect particles larger than about 10 microns with only 85 to 95 percent control efficiency, often producing visible emissions. Hence, fabric filters are usually selected in areas having more stringent control requirements. Typical efficiencies for well operated fabric filters exceed 99 percent, with no visible emissions. The air aspirated from enclosed equipment and hoods is ducted to a fabric filter or, in some cases, one or more cyclones. Rarely are other particulate control devices, such as wet scrubbers and electrostatic precipitators, applied at elevators. Grain dryers present a different sort of control problem because of the large volumes of warm, moist air exhausted. Most dryers are enclosed with a continuously vacuumed polyester or stainless steel screening to collect particulate, with the vacuum usually discharged to a cyclone. Two principal dryer configurations, rack and column, are in use. The majority of dryers manufactured today are of the column type, which has considerably lower emissions than the rack type.[16]

6.4.2.2 Grain Processing Plants - Several grain milling operations, such as receiving, conveying, cleaning and drying, are similar to those at grain elevators. In addition to these, breaking down (milling) the grain or grain by-products for processing through various types of grinding operations is a further source of emissions. The hammermill is the most widely used grinding device at feed mills. Product is recovered from the hammermill with a cyclone collector, which can be a major source of dust emissions. Again, like elevators, mills use a combination of cyclones and fabric filters to conserve product and to control emissions. Drying at a grain mill is accomplished using several types of dryers, including fluidized bed dryers (soybean processing) and flash fired or direct fired dryers (corn milling). These newer dryer types might have lower emissions than the traditional rack or column dryers, but data are insufficient at this time to quantify the difference. The grain pre-cleaning often performed before drying also likely serves to reduce emissions. Emission factors for various grain milling and other processing operations are presented in Table 6.4-6, and the particle size distribution and size specific emission factor for a roaster operation are shown in Table 6.4-7 and Figure 6.4-5. The origins of these emission factors are discussed below.

Emission factor data for feed mill operations are sparse. The factors for receiving, shipping and handling are based on estimates made by experts within the feed industry.[17] The remaining feed mill factors are based on test data in References 2, 18 and 19.

The roasting of carob kibble (or pods), which are ground and used as a chocolate substitute, is similar to coffee roasting. The emission factor and particle size distribution for this operation were derived from References 20 and 21.

Three emission areas for wheat mill processing operations are grain receiving and handling, cleaning house and milling operations. Data from Reference 5 were used to estimate emission factors for grain receiving and

TABLE 6.4-6. TOTAL PARTICULATE EMISSION FACTORS FOR UNCONTROLLED GRAIN PROCESSING OPERATIONS[a]

EMISSION FACTOR RATING: D

Type of Operation	Emission factor	
	kg/Mg	lb/ton
Feed mills		
Receiving	1.3	2.5
Shipping	0.5	1.0
Handling	2.7	5.5
Grinding		
Hammermilling[b]	0.1[c,d]	0.2[c,d]
Flaking[b]	0.1[c]	0.2[d]
Cracking[b]	0.01[c,d]	0.02[c,d]
Pellet cooler[b]	0.2[c]	0.4[c]
Carob kibble roasting	3.0	6.0
Wheat milling		
Receiving	0.5	1.0
Precleaning and handling	2.5	5.0
Cleaning house	-	-
Mill house	35.0	70.0
Durum milling		
Receiving	0.5	1.0
Precleaning and handling	2.5	5.0
Cleaning house	-	-
Mill house	-	-
Rye milling		
Receiving	0.5	1.0
Precleaning and handling	2.5	5.0
Cleaning house	-	-
Mill house	35.0	70.0
Oat milling[e]	1.25	2.5
Rice milling		
Receiving	0.32	0.64
Precleaning and handling	2.5	5.0
Drying[f]	0.15	0.30
Cleaning and mill house	-	-

TABLE 6.4-6 (concluded).

Type of Operation	Emission factor	
	kg/Mg	lb/ton
Soybean milling		
Receiving	0.8	1.6
Handling	2.5	5.0
Cleaning	-	-
Drying[g]	3.6	7.2
Cracking and dehulling	1.7	3.3
Hull grinding	1.0	2.0
Bean conditioning	0.05	0.1
Flaking	0.29	0.57
Meal dryer	0.75	1.5
Meal cooler	0.9	1.8
Bulk loading	0.14	0.27
Dry corn milling		
Receiving	0.5	1.0
Drying[g]	0.25	0.5
Precleaning and handling	2.5	5.0
Cleaning house	3.0	6.0
Degerming and milling	-	-
Wet corn milling		
Receiving	0.5	1.0
Handling	2.5	5.0
Cleaning	3.0	6.0
Drying[h]	0.24	0.48
Bulk loading	-	-

[a] Most emission factors are expressed as weight of dust emitted/unit weight of grain entering the plant, not necessarily the same as amount of material processed by each operation. Dash = no data.

[b] Expressed as weight of dust emitted/unit weight of grain processed.

[c] With cyclones.

[d] Measured on corn processing operations at feed mills.

[e] Represents several sources at one plant, some controlled with cyclones and others with fabric filters.

[f] Average for uncontrolled column dryers; see Table 6.4-2.

[g] Dryer types unknown.

[h] For rotary steam tube dryers.

TABLE 6.4-7. PARTICLE SIZE DISTRIBUTION AND EMISSION FACTORS FOR UNCONTROLLED CAROB KIBBLE ROASTERS[a]

EMISSION FACTOR RATING: E

Aerodynamic particle diameter (um)	Cumulative weight % ≤ stated size	Emission factor[b] (kg/Mg)
2.5	0.6	0.018
6.0	0.7	0.021
10.0	2.0	0.060
15.0	11.5	0.35
Total particulate		3.0[c]

[a] Reference 18.

[b] Expressed as cumulative weight of particulate ≤ corresponding particle size/unit weight of carob kibble roasted.

[c] Reference 21.

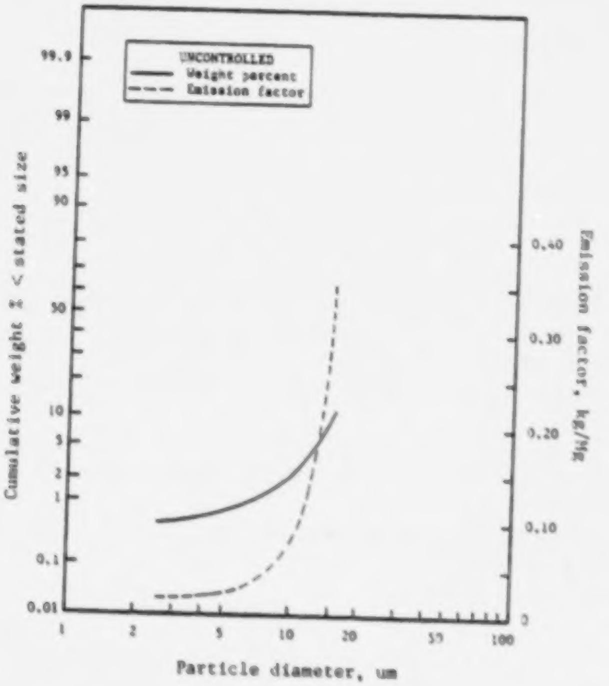

Figure 6.4-5. Cumulative size distribution and emission factors for uncontrolled carob kibble roasters.

handling. Data for the cleaning house are insufficient to estimate an emission factor, and information contained in Reference 2 was used to estimate the emission factor for milling operations. The large emission factor for the milling operation applies to uncontrolled operations. Almost all of the sources involved, however, are equipped with control devices to prevent product losses. Fabric filters are widely used for this purpose.

Durum and rye milling operations are similar to those for wheat milling. Therefore, most of these emission factors are assumed equal to those for wheat mill operations.

The grain unloading, handling and cleaning operations for dry corn milling are similar to those in other grain mills, but the subsequent operations are somewhat different. Also, some drying of corn received at the mill may be necessary before storage. An estimate of the emission factor for drying was obtained from Reference 2. Insufficient information is available to estimate emission factors for degerming and milling.

Information necessary to estimate emissions from oat milling is unavailable, and no emission factors for other grains are considered applicable because oats are reported to be dustier than many other grains. The only emission factor data available are for controlled emissions.

Emission factors for rice milling are based on those for similar operations in other grain handling facilities. Insufficient information is available to estimate emission factors for drying, cleaning and mill house operations.

Information contained in Reference 2 is used to estimate emission factors for soybean mills.

Emissions information on wet corn milling is generally unavailable, in part because of the wide variety of products and the diversity of operations. Receiving, handling and cleaning operations emission factors are assumed to be similar to those for dry corn milling. The drying emission factor is from tests at a wet corn milling plant producing animal feed.[22]

Due to operational similarities between grain milling and processing plants and grain elevators, the control methods used are similar. Both often use cyclones or fabric filters to control emissions from the grain handling operations (e.g., unloading, legs, cleaners, etc.). These same devices are also often used to control emissions from other processing operations. A good example of this is the extensive use of fabric filters in flour mills. However, there are also certain operations within some milling operations that are not amenable to the use of these devices. Therefore, wet scrubbers have found some application, particularly where the effluent gas stream has a high moisture content. Certain other operations have been found to be especially difficult to control, such as rotary dryers in wet corn mills. The various emission control systems that have been applied to operations within the grain milling and processing industry are described in Reference 2.

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18. Written communication from P. Luther, Purina Mills, Inc., St. Louis, MO, to G. LaFlam, PES, Inc., Durham, NC, March 11, 1987.

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About 10 percent of all lime produced is converted to hydrated (slaked) lime. There are two kinds of hydrators, atmospheric and pressure. Atmospheric hydrators, the more prevalent type, are used in continuous mode to produce high calcium and normal dolomitic hydrates. Pressure hydrators, on the other hand, produce only a completely hydrated dolomitic lime and operate only in batch mode. Generally, water sprays or wet scrubbers perform the hydrating process, to prevent product loss. Following hydration, the product may be milled and then conveyed to air separators for further drying and removal of coarse fractions.

In the United States, lime plays a major role in chemical and metallurgical operations. Two of the largest uses are as steel flux and in alkali production. Lesser uses include construction, refractory and agricultural applications.

8.15.2 Emissions And Controls[3-5]

Potential air pollutant emission points in lime manufacturing plants are shown in Figure 8.15-1. Except for gaseous pollutants emitted from kilns, particulate is the only pollutant of concern from most of the operations.

The largest ducted source of particulate is the kiln. Of the various kiln types, fluidized beds have the most uncontrolled particulate emissions, because of the very small feed size combined with high air flow through these kilns. Fluidized bed kilns are well controlled for maximum product recovery. The rotary kiln is second worst in uncontrolled particulate emissions, also because of the small feed size and relatively high air velocities and dust entrainment caused by the rotating chamber. The calcimatic (rotary hearth) kiln ranks third in dust production, primarily because of the larger feed size and the fact that, during calcination, the limestone remains stationary relative to the hearth. The vertical kiln has the lowest uncontrolled dust emissions, due to the large lump feed and the relatively low air velocities and slow movement of material through the kiln.

Some sort of particulate control is generally applied to most kilns. Rudimentary fallout chambers and cyclone separators are commonly used for control of the larger particles. Fabric and gravel bed filters, wet (commonly venturi) scrubbers, and electrostatic precipitators are used for secondary control.

Nitrogen oxides, carbon monoxide and sulfur oxides are all produced in kilns, although the last are the only gaseous pollutant emitted in significant quantities. Not all of the sulfur in the kiln fuel is emitted as sulfur oxides, since some fraction reacts with the materials in the kiln. Some sulfur oxide reduction is also effected by the various equipment used for secondary particulate control.

Product coolers are emission sources only when some of their exhaust gases are not recycled through the kiln for use as combustion air. The trend is away from the venting of product cooler exhaust, however, to maximize fuel use efficiencies. Cyclones, baghouses and wet scrubbers have been employed on coolers for particulate control.

Hydrator emissions are low, because water sprays or wet scrubbers are usually installed to prevent product loss in the exhaust gases. Emissions from pressure hydrators may be higher than from the more common atmospheric hydrators, because the exhaust gases are released intermittently, making control more difficult.

Other particulate sources in lime plants include primary and secondary crushers, mills, screens, mechanical and pneumatic transfer operations, storage piles, and roads. If quarrying is a part of the lime plant operation, particulate may also result from drilling and blasting. Emission factors for some of these operations are presented in Sections 8.19 and 11.2 of this document.

Controlled and uncontrolled emission factors and particle size data for lime manufacturing are given in Tables 8.15-1 through 8.15-3. The size distributions of particulate emissions from controlled and uncontrolled rotary kilns and uncontrolled product loading operations are shown in Figures 8.15-2 and 8.15-3.

TABLE 8.15-1. EMISSION FACTORS FOR LIME MANUFACTURING[a]

EMISSION FACTOR RATING: B

Source	Particulate[b]		Nitrogen oxides		Carbon monoxide		Sulfur dioxide	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Crushers, screens, conveyors, storage piles, unpaved roads, etc.	c	c	Neg	Neg	Neg	Neg	Neg	Neg
Rotary kilns[d]								
Uncontrolled[e]	180	350	1.4	2.8	1	2	f	f
Large diameter cyclone	81	160	1.4	2.8	1	2	f	f
Multiple cyclone	42	83	1.4	2.8	1	2	f	f
Electrostatic precipitator[g]	2.4	4.8	1.4	2.8	1	2	h	h
Venturi scrubber	2.4	4.8	1.4	2.8	1	2	h	h
Gravel bed filter[g]	0.53[i]	1.1[i]	1.4	2.8	1	2	h	h
Multiclone and venturi scrubber[g]	0.44	0.87	1.4	2.8	1	2	h	h
Baghouse	0.45[j]	0.89[j]	1.4	2.8	1	2	h	h
Cyclone and baghouse	0.055	0.11	1.4	2.8	1	2	h	h
Vertical kilns								
Uncontrolled	4	8	NA	NA	NA	NA	NA	NA
Calcimatic kilns[k]								
Uncontrolled	25	50	0.1	0.2	NA	NA	NA	NA
Multiple cyclone	3	6	0.1	0.2	NA	NA	NA	NA
Secondary dust collection[ℓ]	NA	NA	0.1	0.2	NA	NA	NA	NA
Fluidized bed kilns	m	m	NA	NA	NA	NA	NA	NA
Product coolers								
Uncontrolled	20[n]	40[n]	Neg	Neg	Neg	Neg	Neg	Neg
Hydrators (atmospheric)[p]								
Wet scrubber	0.05	0.1	Neg	Neg	Neg	Neg	Neg	Neg
Crusher, screen, hammermill								
Baghouse	0.0005	0.001	Neg	Neg	Neg	Neg	Neg	Neg
Final screen								
Baghouse	0.0004	0.0008	Neg	Neg	Neg	Neg	Neg	Neg
Uncontrolled truck loading								
Limestone								
Open truck	0.75	1.5	Neg	Neg	Neg	Neg	Neg	Neg
Closed truck	0.38	0.76	Neg	Neg	Neg	Neg	Neg	Neg
Lime - closed truck	0.15[j]	0.30[j]	Neg	Neg	Neg	Neg	Neg	Neg

TABLE 8.15-1 (cont.).

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[a] References 4-7. Factors for kilns and coolers are per unit of lime produced. Divide by two to obtain factors per unit of limestone feed to the kiln. Factors for hydrators are per unit of hydrated lime produced. Multiply by 1.25 to obtain factors per unit of lime feed to the hydrator. Neg = negligible. NA = not available.

[b] Emission Factor Rating = D.

[c] Factors for these operations are presented in Sections 8.19 and 11.2 of this document.

[d] For coal fired rotary kilns only.

[e] No particulate control except for settling that may occur in stack breeching and chimney base.

[f] Sulfur dioxide may be estimated by a material balance using fuel sulfur content.

[g] Combination coal/gas fired rotary kilns only.

[h] When scrubbers are used, < 5% of the fuel sulfur will be emitted as SO_2 even with high sulfur coal. When other secondary collection devices are used, about 20% of the fuel sulfur will be emitted as SO_2 with high sulfur fuels, and < 10% with low sulfur fuels.

[i] Emission Factor Rating = E.

[j] Emission Factor Rating = C.

[k] Calcimatic kilns generally have stone preheaters. Factors are for emissions after the kiln exhaust passes through a preheater.

[l] Fabric filters and venturi scrubbers have been used on calcimatic kilns. No data are available on particulate emissions after secondary control.

[m] Fluidized bed kilns must have sophisticated dust collection equipment for process economics, hence particulate emissions will depend on efficiency of the control equipment installed.

[n] Some or all cooler exhaust typically is used in kiln as combustion air. Emissions will result only from that fraction not recycled to kiln.

[p] Typical particulate loading for atmospheric hydrators following water sprays or wet scrubbers. Limited data suggest particulate emissions from pressure hydrators may be approximately 1 kg/Mg (2 lb/ton) of hydrate produced, after wet collectors.

8.19.2 CRUSHED STONE PROCESSING

8.19.2.1 Process Description[1]

Major rock types processed by the rock and crushed stone industry include limestone, dolomite, granite, traprock, sandstone, quartz and quartzite. Minor types include calcareous marl, marble, shell and slate. Industry classifications vary considerably and, in many cases, do not reflect actual geological definitions.

Rock and crushed stone products generally are loosened by drilling and blasting, then are loaded by power shovel or front end loader and transported by heavy earth moving equipment. Techniques used for extraction vary with the nature and location of the deposit. Further processing may include crushing, screening, size classification, material handling, and storage operations. All of these processes can be significant sources of dust emissions if uncontrolled. Some processing operations also include washing, depending on rock type and desired product.

Quarried stone normally is delivered to the processing plant by truck and is dumped into a hoppered feeder, usually a vibrating grizzly type, or onto screens, as illustrated in Figure 8.19.2-1. These screens separate or scalp large boulders from finer rocks that do not require primary crushing, thus reducing the load to the primary crusher. Jaw, or gyratory, crushers are usually used for initial reduction. The crusher product, normally 7.5 to 30 centimeters (3 to 12 inches) in diameter, and the grizzly throughs (undersize material) are discharged onto a belt conveyor and usually are transported either to secondary screens and crushers or to a surge pile for temporary storage.

Further screening generally separates the process flow into either two or three fractions (oversize, undersize and throughs) ahead of the secondary crusher. The oversize is discharged to the secondary crusher for further reduction, and the undersize usually bypasses the secondary crusher. The throughs sometimes are separated, because they contain unwanted fines, and are stockpiled as crusher run material. Gyratory crushers or cone crushers are commonly used for secondary crushing, although impact crushers are sometimes found.

The product of the secondary crushing stage, usually 2.5 centimeters (1 inch) diameter or less, is transported to secondary screens for further sizing. Oversize material is sent back for recrushing. Depending on rock type and desired product, tertiary crushing or grinding may be necessary, usually using cone crushers or hammermills. (Rod mills, ball mills and hammer mills normally are used in milling operations, which are not considered a part of the construction aggregate industry.) The product from tertiary crushing may be conveyed to a classifier, such as a dry vibrating screen system, or to an air separator. Any oversize is returned to the tertiary crusher for further reduction. At this point, end products of the desired grade are conveyed or trucked directly to finished product bins or to open area stockpiles.

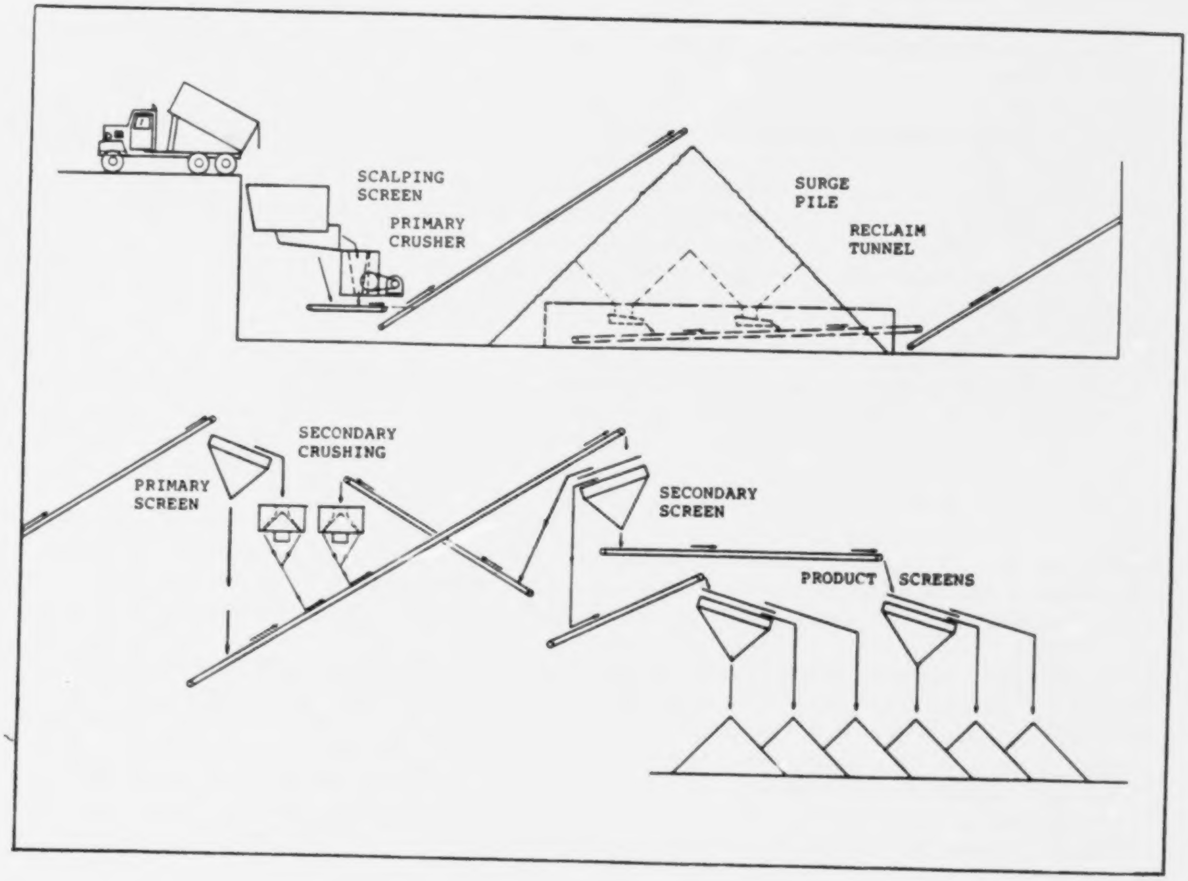
SCALPING SCREEN
PRIMARY CRUSHER
SURGE PILE
RECLAIM TUNNEL
PRIMARY SCREEN
SECONDARY CRUSHING
SECONDARY SCREEN
PRODUCT SCREENS

FIGURE 8.19.2-1. Typical stone processing plant.

In certain cases, stone washing is required to meet particular end product specifications or demands, as with concrete aggregate processing. Crushed and broken stone normally are not milled but are screened and shipped to the consumer after secondary or tertiary crushing.

8.19.2.2 Emissions And Controls[1-3]

Dust emissions occur from many operations in stone quarrying and processing. A substantial portion of these emissions consists of heavy particles that may settle out within the plant. As in other operations, crushed stone emission sources may be categorized as either process sources or fugitive dust sources. Process sources include those for which emissions are amenable to capture and subsequent control. Fugitive dust sources generally involve the reentrainment of settled dust by wind or machine movement. Factors affecting emissions from either source category include the type, quantity and surface moisture content of the stone processed; the type of equipment and operating practices employed; and topographical and climatic factors.

Of geographic and seasonal factors, the primary variables affecting uncontrolled particulate emissions are wind and material moisture content. Wind parameters vary with geographical location, season and weather. It can be expected that the level of emissions from unenclosed sources (principally fugitive dust sources) will be greater during periods of high winds. The material moisture content also varies with geographic location, season and weather. Therefore, the levels of uncontrolled emissions from both process emission sources and fugitive dust sources generally will be greater in arid regions of the country than in temperate ones, and greater during the summer months because of a higher evaporation rate.

The moisture content of the material processed can have a substantial effect on uncontrolled emissions. This is especially evident during mining, initial material handling, and initial plant process operations such as primary crushing. Surface wetness causes fine particles to agglomerate on, or to adhere to, the faces of larger stones, with a resulting dust suppression effect. However, as new fine particles are created by crushing and attrition, and as the moisture content is reduced by evaporation, this suppressive effect diminishes and may disappear. Depending on the geographic and climatic conditions, the moisture content of mined rock may range from nearly zero to several percent. Since moisture content is usually expressed on a basis of overall weight percent, the actual moisture amount per unit area will vary with the size of the rock being handled. On a constant mass fraction basis, the per unit area moisture content varies inversely with the diameter of the rock. Therefore, the suppressive effect of the moisture depends on both the absolute mass water content and the size of the rock product. Typically, a wet material will contain 1.5 to 4 percent water or more.

There are a large number of material, equipment and operating factors which can influence emissions from crushing. These include: (1) rock type, (2) feed size and distribution, (3) moisture content, (4) throughput rate, (5) crusher type, (6) size reduction ratio, and (7) fines content. Insufficient data are available to present a matrix of rock crushing emission factors detailing the above classifications and variables. Data available from which to prepare emission factors also vary considerably, for both extractive testing and plume profiling. Emission factors from extractive testing are generally higher than those based upon plume profiling tests, but they have a greater degree of reliability. Some test data for primary crushing indicate higher emissions than from secondary crushing, although factors affecting emission rates and visual observations suggest that the secondary crushing emission factor, on a throughput basis, should be higher. Table 8.19.2-1 shows single factors for either primary or secondary crushing reflecting a combined data base. An emission factor for tertiary crushing is given, but it is based on extremely limited data. All factors are rated low because of the limited and highly variable data base.

TABLE 8.19.2-1. UNCONTROLLED PARTICULATE EMISSION FACTORS FOR CRUSHING OPERATIONS[a]

Type of crushing[b]	Particulate		Emission Factor Rating
	$\leq$ 30 um kg/Mg (lb/ton)	$\leq$ 10 um kg/Mg (lb/ton)	
Primary or secondary			
Dry material	0.14 (0.28)	0.0085 (0.017)	D
Wet material[c]	0.009 (0.018)	-	D
Tertiary dry material[d]	0.93 (1.85)	-	E

[a] Based on actual feed rate of raw material entering the particular operation. Emissions will vary by rock type, but data available are insufficient to characterize these phenomena. Dash = no data.

[b] References 4-5. Typical control efficiencies for cyclone, 70 - 80%; fabric filter, 99%; wet spray systems, 70 - 90%.

[c] References 5-6. Refers to crushing of rock either naturally wet or moistened to 1.5 - 4 weight % with wet suppression techniques.

[d] Range of values used to calculate emission factor is 0.0008 - 1.38 kg/Mg.

Emission factor estimates for stone quarry blasting operations are not presented here because of the sparsity and unreliability of available test data. While a procedure for estimating blasting emissions is presented in Section 8.24, Western Surface Coal Mines, that procedure should not be applied to stone quarries because of dissimilarities in blasting techniques, material blasted and size of blast areas.

There are no screening emission factors presented in this Section. However, the screening emission factors given in Section 8.19.1, Sand and Gravel Processing, should be similar to those expected from screening crushed rock. Milling of fines is also not included in this Section as this operation is normally associated with non construction aggregate end uses and will be covered elsewhere in the future when information is adequate.

Open dust source (fugitive dust) emission factors for stone quarrying and processing are presented in Table 8.19.2-2. These factors have been determined

TABLE 8.19.2-2. UNCONTROLLED PARTICULATE EMISSION FACTORS FOR OPEN DUST SOURCES AT CRUSHED STONE PLANTS

Operation	Material	Emissions by particle size range (aerodynamic diameter)[a]			Emission Factor Rating
		TSP ≤ 30 um	PM_{10} ≤ 10 um	Units[b]	
Wet quarry drilling	Unfractured stone[c]	0.4 (0.0008)	0.04 (0.0001)	g/Mg (lb/ton)	E
Batch drop					
Truck unloading	Fractured stone[c]	0.17 (0.0003)	0.008 (0.00002)	g/Mg (lb/ton)	D
Truck loading					
Conveyor	Crushed stone[d]	0.17 (0.0003)	0.05 (0.0001)	g/Mg (lb/ton)	E
Front end loader	Crushed stone[e]	29.0 (0.06)	NA	g/Mg (lb/ton)	E
Conveying					
Tunnel belt	Crushed stone[c]	1.7 (0.0034)	0.11 (0.0002)	g/Mg (lb/ton)	E
Unpaved haul roads		f	f		
Blasting	Quarried stone	g	g		

[a] Total suspended particulate (TSP) is that measured by a standard high volume sampler (See Section 11.2). Use of empirical equations in Chapter 11 is preferred to single value factors in this Table. Factors in this Table are provided for convenience in quick approximations and/or for occasions when equation variables can not be reasonably estimated. NA = not available.

[b] Expressed as g/Mg (lb/ton) of material through primary crusher, except for front end loading, which is g/Mg (lb/ton) of material transferred.

[c] Reference 2.

[d] Reference 3.

[e] Reference 6.

[f] See Section 11.2 for empirical equations.

[g] Not presented because of sparsity and unreliability of test data.

through tests at various quarries and processing plants.[6-7] The single valued open dust emission factors given in Table 8.19.2-2 may be used when no other information exists. Empirically derived emission factor equations presented in Section 11.2 of this document are preferred and should be used when possible. Because these predictive equations allow the adjustment of emission factors for specific source conditions, these equations should be used instead of those in Table 8.19.2-2, whenever emission estimates applicable to specific stone quarrying and processing facility sources are needed. Chapter 11.2 provides measured properties of crushed limestone, as required for use in the predictive emission factor equations.

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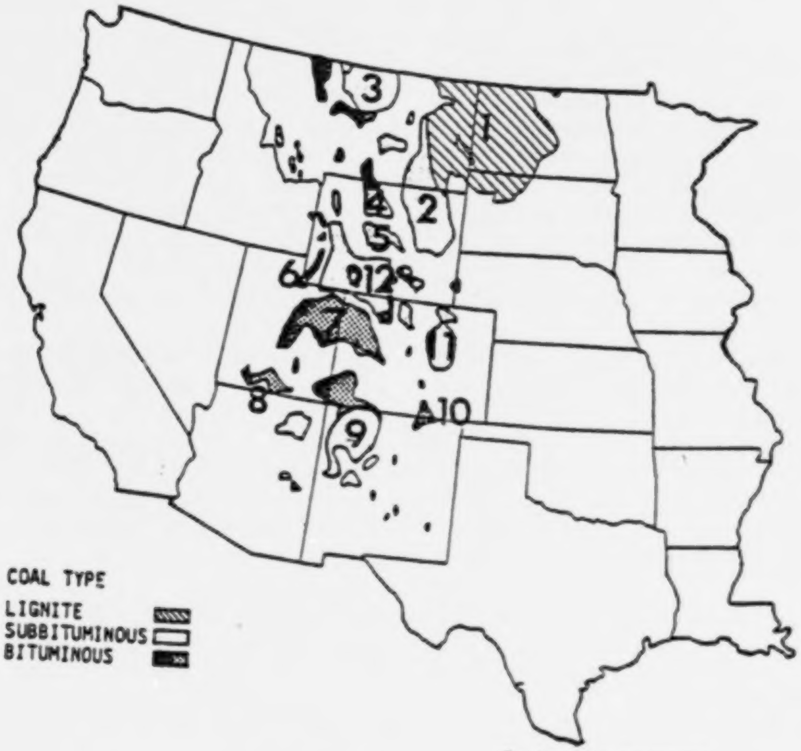
8.24 WESTERN SURFACE COAL MINING

8.24.1 General[1]

There are 12 major coal fields in the western states (excluding the Pacific Coast and Alaskan fields), as shown in Figure 8.24-1. Together, they account for more than 64 percent of the surface minable coal reserves



	Coal field	Strippable reserves (10^6 tons)
1	Fort Union	23,529
2	Powder River	56,727
3	North Central	All underground
4	Bighorn Basin	All underground
5	Wind River	3
6	Hams Fork	1,000
7	Uinta	308
8	Southwestern Utah	224
9	San Juan River	2,318
10	Raton Mesa	All underground
11	Denver	All underground
12	Green River	2,120

Figure 8.24-1. Coal fields of the western U.S.[3]

in the United States.[2] The 12 coal fields have varying characteristics which may influence fugitive dust emission rates from mining operations, including overburden and coal seam thicknesses and structure, mining equipment, operating procedures, terrain, vegetation, precipitation and surface moisture, wind speeds and temperatures. The operations at a typical western surface mine are shown in Figure 8.24-2. All operations that involve movement of soil, coal, or equipment, or exposure of erodible surfaces, generate some amount of fugitive dust.

The initial operation is removal of topsoil and subsoil with large scrapers. The topsoil is carried by the scrapers to cover a previously mined and regraded area as part of the reclamation process or is placed in temporary stockpiles. The exposed overburden, the earth which is between the topsoil and the coal seam, is leveled, drilled and blasted. Then the overburden material is removed down to the coal seam, usually by a dragline or a shovel and truck operation. It is placed in the adjacent mined cut, forming a spoils pile. The uncovered coal seam is then drilled and blasted. A shovel or front end loader loads the broken coal into haul trucks, and it is taken out of the pit along graded haul roads to the tipple, or truck dump. Raw coal sometimes may be dumped onto a temporary storage pile and later rehandled by a front end loader or bulldozer.

At the tipple, the coal is dumped into a hopper that feeds the primary crusher, then is conveyed through additional coal preparation equipment such as secondary crushers and screens to the storage area. If the mine has open storage piles, the crushed coal passes through a coal stacker onto the pile. The piles, usually worked by bulldozers, are subject to wind erosion. From the storage area, the coal is conveyed to a train loading facility and is put into rail cars. At a captive mine, coal will go from the storage pile to the power plant.

During mine reclamation, which proceeds continuously throughout the life of the mine, overburden spoils piles are smoothed and contoured by bulldozers. Topsoil is placed on the graded spoils, and the land is prepared for revegetation by furrowing, mulching, etc. From the time an area is disturbed until the new vegetation emerges, all disturbed areas are subject to wind erosion.

8.24.2 Emissions

Predictive emission factor equations for open dust sources at western surface coal mines are presented in Tables 8.24-1 and 8.24-2. Each equation is for a single dust generating activity, such as vehicle traffic on unpaved roads. The predictive equation explains much of the observed variance in emission factors by relating emissions to three sets of source parameters: 1) measures of source activity or energy expended (e.g., speed and weight of a vehicle traveling on an unpaved road); 2) properties of the material being disturbed (e.g., suspendable fines in the surface material of an unpaved road); and 3) climate (in this case, mean wind speed).

The equations may be used to estimate particulate emissions generated per unit of source extent (e.g., vehicle distance traveled or mass of material transferred).

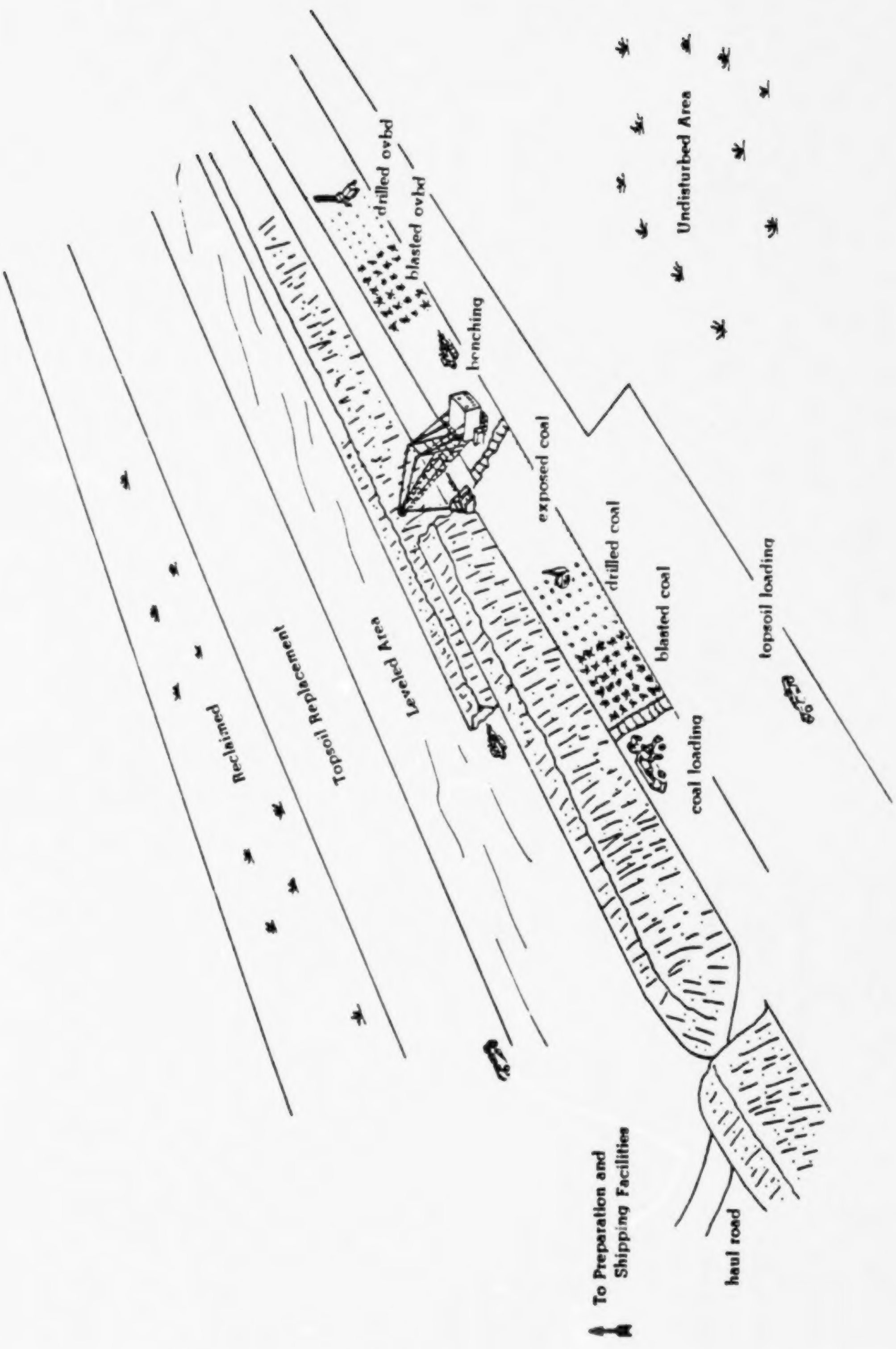

drilled ovbd
blasted ovbd
benching
exposed coal
drilled coal
blasted coal
topsoil loading
coal loading
Undisturbed Area
Reclaimed
Topsoil Replacement
Leveled Area
To Preparation and Shipping Facilities
haul road

Figure 8.24-2. Operations at typical western surface coal mines.

TABLE 8.24-1. EMISSION FACTOR EQUATIONS FOR UNCONTROLLED OPEN DUST SOURCES AT WESTERN SURFACE COAL MINES (METRIC UNITS)[a]

Operation	Material	Emissions by particle size range (aerodynamic diameter)[b,c] TSP ≤ 30 um	≤ 15 um	≤ 10 um[d]	<2.5 um/TSP[e]	Units	Emission Factor Rating
Blasting	Coal or overburden	$0.00022^{1.5}$	NA	0.52[e]	NA	kg/blast	C
Truck loading	Coal	$\frac{0.580}{(M)^{1.2}}$	$\frac{0.0596}{(M)^{0.9}}$	0.75	0.019	kg/Mg	B
Bulldozing	Coal	$\frac{35.6\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{8.44\ (s)^{1.5}}{(M)^{1.4}}$	0.75	0.022	kg/hr	B
	Overburden	$\frac{2.6\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{0.45\ (s)^{1.5}}{(M)^{1.4}}$	0.75	0.105	kg/hr	B
Dragline	Overburden	$\frac{0.0046\ (d)^{1.1}}{(M)^{0.3}}$	$\frac{0.0029\ (d)^{0.7}}{(M)^{0.3}}$	0.75	0.017	kg/m³	B
Scraper (travel mode)		$9.6 \times 10^{-6}\ (s)^{1.3}\ (W)^{2.4}$	$2.2 \times 10^{-6}\ (s)^{1.4}\ (W)^{2.5}$	0.60	0.026	kg/VKT	A
Grading		$0.0034\ (S)^{2.5}$	$0.0056\ (S)^{2.0}$	0.60	0.031	kg/VKT	B
Vehicle traffic (light/medium duty)		$\frac{1.63}{(M)^{4.0}}$	$\frac{1.05}{(M)^{4.3}}$	0.60	0.040	kg/VKT	B
Haul truck		$0.0019\ (w)^{3.4}\ (L)^{0.2}$	$0.0014\ (w)^{3.5}$	0.60	0.017	kg/VKT	A
Active storage pile (wind erosion and maintenance)	Coal	1.8 u	NA	NA	NA	$\frac{kg}{(hectare)(hr)}$	C[f]

[a] Reference 1, except for coal storage pile equation from Reference 4. TSP = total suspended particulate. VKT = vehicle kilometers traveled. NA = not available.

[b] TSP denotes what is measured by a standard high volume sampler (see Section 11.2).

[c] Symbols for equations:

A = horizontal area, with blasting depth $\leq$ 21 m. Not for vertical face of a bench.
M = material moisture content (%)
s = material silt content (%)
u = wind speed (m/sec)
d = drop height (m)
W = mean vehicle weight (Mg)
S = mean vehicle speed (kph)
w = mean number of wheels
L = road surface silt loading (g/m²)

[d] Multiply the $\leq$15 um equation by this fraction to determine emissions.

[d] Multiply the TSP predictive equation by this fraction to determine emissions in the $\leq$2.5 um size range.

[e] Rating applicable to Mine Types I, II and IV (see Tables 8.24-5 and 8.24-6).

TABLE 8.24-2. EMISSION FACTOR EQUATIONS FOR UNCONTROLLED OPEN DUST SOURCES AT WESTERN SURFACE COAL MINES (ENGLISH UNITS)[a]

Operation	Material	Emissions by particle size range (aerodynamic diameter)[b,c]				Units	Emission Factor Rating
		TSP $\leq$30 um	$\leq$15 um	$\leq$10 um[d]	$\leq$2.5 um/TSP[e]		
Blasting	Coal or overburden	$0.0005A^{1.5}$	NA	0.52[e]	NA	lb/blast	C
Truck loading	Coal	$\frac{1.16}{(M)^{1.2}}$	$\frac{0.119}{(M)^{0.9}}$	0.75	0.019	lb/ton	B
Bulldozing	Coal	$\frac{78.4\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{18.6\ (s)^{1.5}}{(M)^{1.4}}$	0.75	0.022	lb/hr	B
	Overburden	$\frac{5.7\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{1.0\ (s)^{1.5}}{(M)^{1.4}}$	0.75	0.105	lb/hr	B
Dragline	Overburden	$\frac{0.0021\ (d)^{1.1}}{(M)^{0.3}}$	$\frac{0.0021\ (d)^{0.7}}{(M)^{0.3}}$	0.75	0.017	lb/yd^3	B
Scraper (travel model)		$2.7 \times 10^{-5}\ (s)^{1.3}\ (W)^{2.4}$	$6.2 \times 10^{-6}\ (s)^{1.4}\ (W)^{2.5}$	0.60	0.026	lb/VMT	A
Grading		$0.040\ (S)^{2.5}$	$0.051\ (S)^{2.0}$	0.60	0.031	lb/VMT	B
Vehicle traffic (light/medium duty)		$\frac{5.79}{(M)^{4.0}}$	$\frac{3.72}{(M)^{4.3}}$	0.60	0.040	lb/VMT	B
Haul truck		$0.0067\ (w)^{3.4}\ (L)^{0.2}$	$0.0051\ (w)^{3.5}$	0.60	0.017	lb/VMT	A
Active storage pile (wind erosion and maintenance)	Coal	1.6 u	NA	NA	NA	$\frac{lb}{(acre)(hr)}$	C[f]

[a] Reference 1, except for coal storage pile equation from Reference 4. TSP = total suspended particulate. VMT = vehicle miles traveled. NA = not available.

[b] TSP denotes what is measured by a standard high volume sampler (see Section 11.2).

[c] Symbols for equations:

A = horizontal area, with blasting depth $\leq$70 ft. Not for vertical face of a bench

M = material moisture content (%)

s = material silt content (%)

u = wind speed (m/sec)

d = drop height (ft)

W = mean vehicle weight (tons)

S = mean vehicle speed (mph)

w = mean number of wheels

L = road surface silt loading (g/m^2)

[d] Multiply the $\leq$15 um equation by this fraction to determine emissions.

[e] Multiply the TSP predictive equation by this fraction to determine emissions in the $\leq$2.5 um size range.

[f] Rating applicable to Mine Types I, II and IV (see Tables 8.24-5 and 8.24-6).

The equations were developed through field sampling of various western surface mine types and are thus applicable to any of the surface coal mines located in the western United States.

In Tables 8.24-1 and 8.24-2, the assigned quality ratings apply within the ranges of source conditions that were tested in developing the equations, given in Table 8.24-3. However, the equations are derated one letter value (e. g., A to B) if applied to eastern surface coal mines.

TABLE 8.24-3. TYPICAL VALUES FOR CORRECTION FACTORS APPLICABLE TO THE PREDICTIVE EMISSION FACTOR EQUATIONS[a]

Source	Correction factor	Number of test samples	Range	Geometric mean	Units
Coal loading	Moisture	7	6.6 - 38	17.8	%
Bulldozers					
Coal	Moisture	3	4.0 - 22.0	10.4	%
	Silt	3	6.0 - 11.3	8.6	%
Overburden	Moisture	8	2.2 - 16.8	7.9	%
	Silt	8	3.8 - 15.1	6.9	%
Dragline	Drop distance	19	1.5 - 30	8.6	m
	" "		5 - 100	28.1	ft
	Moisture	7	0.2 - 16.3	3.2	%
Scraper	Silt	10	7.2 - 25.2	16.4	%
	Weight	15	33 - 64	48.8	Mg
	"		36 - 70	53.8	ton
Grader	Speed	7	8.0 - 19.0	11.4	kph
	"		5.0 - 11.8	7.1	mph
Light/medium duty vehicle	Moisture	7	0.9 - 1.7	1.2	%
Haul truck	Wheels	29	6.1 - 10.0	8.1	number
	Silt loading	26	3.8 - 254	40.8	g/m^2
	" "		34 - 2270	364	lb/ac

[a] Reference 1.

In using the equations to estimate emissions from sources found in a specific western surface mine, it is necessary that reliable values for correction parameters be determined for the specific sources of interest, if the assigned quality ranges of the equations are to be applicable. For example, actual silt content of coal or overburden measured at a facility should be used instead of estimated values. In the event that site specific values for correction parameters cannot be obtained, the appropriate geometric mean values from Table 8.24-3 may be used, but the assigned quality rating of each emission factor equation is reduced by one level (e.g., A to B).

Emission factors for open dust sources not covered in Table 8.24-3 are in Table 8.24-4. These factors were determined through source testing at various western coal mines.

The factors in Table 8.24-4 for mine locations I through V were developed for specific geographical areas. Tables 8.24-5 and 8.24-6 present characteristics of each of these mines (areas). A "mine specific" emission factor should be used only if the characteristics of the mine for which an emissions estimate is needed are very similar to those of the mine for which the emission factor was developed. The other (nonspecific) emission factors were developed at a variety of mine types and thus are applicable to any western surface coal mine.

As an alternative to the single valued emission factors given in Table 8.24-4 for train or truck loading and for truck or scraper unloading, two empirically derived emission factor equations are presented in Section 11.2.3 of this document. Each equation was developed for a source operation (i.e., batch drop and continuous drop, respectively), comprising a single dust generating mechanism which crosses industry lines.

Because the predictive equations allow emission factor adjustment to specific source conditions, the equations should be used in place of the factors in Table 8.24-4 for the sources identified above, if emission estimates for a specific western surface coal mine are needed. However, the generally higher quality ratings assigned to the equations are applicable only if 1) reliable values of correction parameters have been determined for the specific sources of interest and 2) the correction parameter values lie within the ranges tested in developing the equations. Table 8.24-3 lists measured properties of aggregate materials which can be used to estimate correction parameter values for the predictive emission factor equations in Chapter 11, in the event that site specific values are not available. Use of mean correction parameter values from Table 8.24-3 reduces the quality ratings of the emission factor equations in Chapter 11 by one level.

TABLE 8.24-4. UNCONTROLLED PARTICULATE EMISSION FACTORS FOR OPEN DUST SOURCES AT WESTERN SURFACE COAL MINES

Source	Material	Mine location[a]	TSP emission factor[b]	Units	Emission Factor Rating
Drilling	Overburden	Any	1.3	lb/hole	B
			0.59	kg/hole	B
	Coal	V	0.22	lb/hole	E
			0.10	kg/hole	E
Topsoil removal by scraper	Topsoil	Any	0.058	lb/T	E
			0.029	kg/Mg	E
		IV	0.44	lb/T	D
			0.22	kg/Mg	D
Overburden replacement	Overburden	Any	0.012	lb/T	C
			0.0060	kg/Mg	C
Truck loading by power shovel (batch drop)[c]	Overburden	V	0.037	lb/T	C
			0.018	kg/Mg	C
Train loading (batch or continuous drop)[c]	Coal	Any	0.028	lb/T	D
			0.014	kg/Mg	D
		III	0.0002	lb/T	D
			0.0001	kg/Mg	D
Bottom dump truck unloading (batch drop)[c]	Overburden	V	0.002	lb/T	E
			0.001	kg/T	E
	Coal	IV	0.027	lb/T	E
			0.014	kg/Mg	E
		III	0.005	lb/T	E
			0.002	kg/Mg	E
		II	0.020	lb/T	E
			0.010	kg/Mg	E
		I	0.014	lb/T	D
			0.0070	kg/Mg	D
		Any	0.066	lb/T	D
			0.033	kg/Mg	D
End dump truck unloading (batch drop)[c]	Coal	V	0.007	lb/T	E
			0.004	kg/Mg	E
Scraper unloading (batch drop)[c]	Topsoil	IV	0.04	lb/T	C
			0.02	kg/Mg	C
Wind erosion of exposed areas	Seeded land, stripped overburden, graded overburden	Any	0.38	$\frac{T}{(acre)(yr)}$	C
			0.85	$\frac{Mg}{(hectare)(yr)}$	C

---

[a] Roman numerals I through V refer to specific mine locations for which the corresponding emission factors were developed (Reference 4). Tables 8.24-4 and 8.24-5 present characteristics of each of these mines. See text for correct use of these "mine specific" emission factors. The other factors (from Reference 5 except for overburden drilling from Reference 1) can be applied to any western surface coal mine.

[b] Total suspended particulate (TSP) denotes what is measured by a standard high volume sampler (see Section 11.2).

[c] Predictive emission factor equations, which generally provide more accurate estimates of emissions, are presented in Chapter 11.

TABLE 8.24-5. GENERAL CHARACTERISTICS OF SURFACE COAL MINES REFERRED TO IN TABLE 8.24-4[a]

Mine	Location	Type of coal mined	Terrain	Vegetative cover	Surface soil type and erodibility index	Mean wind speed m/s	Mean wind speed mph	Mean annual precipitation cm	Mean annual precipitation in.
I	N.W. Colorado	Subbitum.	Moderately steep	Moderate, sagebrush	Clayey, loamy (71)	2.3	5.1	38	15
II	S.W. Wyoming	Subbitum.	Semirugged	Sparse, sagebrush	Arid soil with clay and alkali or carbonate accumulation (86)	6.0	13.4	36	14
III	S.E. Montana	Subbitum.	Gently rolling to semirugged	Sparse, moderate, prairie grassland	Shallow clay loamy deposits on bedrock (47)	4.8	10.7	28 - 41	11 - 16
IV	Central North Dakota	Lignite	Gently rolling	Moderate, prairie grassland	Loamy, loamy to sandy (71)	5.0	11.2	43	17
V	N.E. Wyoming	Subbitum.	Flat to gently rolling	Sparse, sagebrush	Loamy, sandy, clayey, and clay loamy (102)	6.0	13.4	36	14

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[a] Reference 4.

TABLE 8.24-6. OPERATING CHARACTERISTICS OF THE COAL MINES REFERRED TO IN TABLE 8.24-4[a]

Parameter	Required information	Units	Mine I	II	III	IV	V
Production rate	Coal mined	10^6 T/yr	1.13	5.0	9.5	3.8	12.0[b]
Coal transport	Avg. unit train frequency	per day	NA	NA	2	NA	2
Stratigraphic data	Overburden thickness	ft	21	80	90	65	35
	Overburden density	lb/yd^3	4000	3705	3000	-	-
	Coal seam thicknesses	ft	9,35	15,9	27	2,4,8	70
	Parting thicknesses	ft	50	15	NA	32,16	NA
	Spoils bulking factor	%	22	24	25	20	-
	Active pit depth	ft	52	100	114	80	105
Coal analysis data	Moisture	%	10	18	24	38	30
	Ash	%, wet	8	10	8	7	6
	Sulfur	%, wet	0.46	0.59	0.75	0.65	0.48
	Heat content	Btu/lb	11000	9632	8628	8500	8020
Surface disposition	Total disturbed land	acre	168	1030	2112	1975	217
	Active pit	acre	34	202	87	-	71
	Spoils	acre	57	326	144	-	100
	Reclaimed	acre	100	221	950	-	100
	Barren land	acre	-	30	455	-	-
	Associated disturbances	acre	12	186	476	-	46
Storage	Capacity	ton	NA	NA	-	NA	48000
Blasting	Frequency, coal	per week	4	4	3	7	7[b]
	Frequency, overburden	per week	3	0.5	3	NA	7[b]
	Area blasted, coal	ft^2	16000	40000	-	30000	-
	Area blasted, overburden	ft^2	20000	-	-	NA	-

[a] Reference 4. NA = not applicable. Dash = not available.

[b] Estimate.

References for Section 8.24

1. K. Axetell and C. Cowherd, Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources, 2 Volumes, EPA Contract No. 68-03-2924, U. S. Environmental Protection Agency, Cincinnati, OH, July 1981.

2. Reserve Base of U. S. Coals by Sulfur Content: Part 2, The Western States, IC8693, Bureau of Mines, U. S. Department of the Interior, Washington, DC, 1975.

3. Bituminous Coal and Lignite Production and Mine Operations - 1978, DOE/EIA-0118(78), U. S. Department of Energy, Washington, DC, June 1980.

4. K. Axetell, Survey of Fugitive Dust from Coal Mines, EPA-908/1-78-003, U. S. Environmental Protection Agency, Denver, CO, February 1978.

5. D. L. Shearer, *et al.*, Coal Mining Emission Factor Development and Modeling Study, Amax Coal Company, Carter Mining Company, Sunoco Energy Development Company, Mobil Oil Corporation, and Atlantic Richfield Company, Denver, CO, July 1981.

CHAPTER 11. MISCELLANEOUS SOURCES

This chapter contains emission factor information on those source categories that differ substantially from, and hence cannot be grouped with, the other "stationary" sources discussed in this publication. These miscellaneous emitters, both natural and manmade, are almost exclusively area sources, with their pollutant generating process(es) dispersed over large land areas. Another characteristic of these sources is the inapplicability, in most cases, of conventional control methods, such as wet/dry equipment, fuel switching, process changes, etc. Instead, control of these emissions, where possible at all, may include such techniques as modification of agricultural burning practices, paving with asphalt or concrete, or stabiliation of dirt roads. Finally, miscellaneous sources generally emit pollutants intermittently, when compared to most stationary point sources. For example, a wildfire may emit large quantities of particulate and carbon monoxide for several hours or even days. But, when measured against a continuous emitter, such as a sulfuric acid plant, over a long period of time, its emissions may seem relatively minor. Effects on air quality may also be of relatively short duration.

11.1 Wildfires And Prescribed Burning

11.1.1 General[1]

A wildfire is a large scale natural combustion process that consumes various ages, size and types of flora growing outdoors in a geographical area. Consequently, wildfires are potential sources of large amounts of air pollutants that should be considered when trying to relate emissions to air quality.

The size and intensity, even the occurrence, of a wildfire depend directly on such variables as meteorological conditions, the species of vegetation involved and their moisture content, and the weight of consumable fuel per acre (available fuel loading). Once a fire begins, the dry combustible material is consumed first. If the energy release is large and of sufficient duration, the drying of green, live material occurs, with subsequent burning of this material as well. Under proper environmental and fuel conditions, this process may initiate a chain reaction that results in a widespread conflagration.

The complete combustion of wildland fuels (forests, grasslands, wetlands) require a heat flux (temperature gradient), adequate oxygen supply, and sufficient burning time. The size and quantity of wildland fuels, meteorological conditions, and topograhic features interact to modify the burning behavior as the fire spreads, and the wildfire will attain different degrees of combustion efficiency during its lifetime.

The importance of both fuel type and fuel loading on the fire process can not be overemphasized. To meet the pressing need for this kind of information, the U. S. Forest Service is developing a model of a nationwide fuel identification system that will provide estimates of fuel loading by size class. Further, the environmental parameters of wind, slope and expected moisture changes have been superimposed on this fuel model and incorporated into a National Fire Danger Rating System (NFDRS). This system considers five classes of fuel, the components of which are selected on the basis of combustibility, response of dead fuels to moisture, and whether the living fuels are herbaceous (grasses, brush) or woody (trees, shrubs).

Most fuel loading figures are based on values for "available fuel," that is, combustible material that will be consumed in a wildfire under specific weather conditions. Available fuel values must not be confused with corresponding values for either "total fuel" (all the combustible material that would burn under the most severe weather and burning conditions) or "potential fuel" (the larger woody material that remains even after an extremely high intensity wildfire). It must be emphasized, however, that the various methods of fuel identification are of value only when they are related to the existing fuel quantity, the quantity consumed by the fire, and the geographic area and conditions under which the fire occurs.

For the sake of conformity and convenience, fuel loadings are estimated for the vegetation in the U. S. Forest Service Regions are presented in Table 11.1-1. Figure 11.1-1 illustrates these areas and regions.

TABLE 11.1-1. SUMMARY OF ESTIMATED FUEL CONSUMED BY WILDFIRES[a]

National region[b]	Estimated average fuel loading	
	Mg/hectare	ton/acre
Rocky Mountain	83	37
Region 1: Northern	135	60
Region 2: Rocky Mountain	67	30
Region 3: Southwestern	22	10
Region 4: Intermountain	40	8
Pacific	43	19
Region 5: California	40	18
Region 6: Pacific Northwest	135	60
Region 10: Alaska	36	16
Coastal	135	60
Interior	25	11
Southern	20	9
Region 8: Southern	20	9
Eastern	25	11
North central	25	11
Region 9: Conifers	22	10
Hardwoods	27	12

[a] Reference 1.

[b] See Figure 11.1-1 for region boundaries

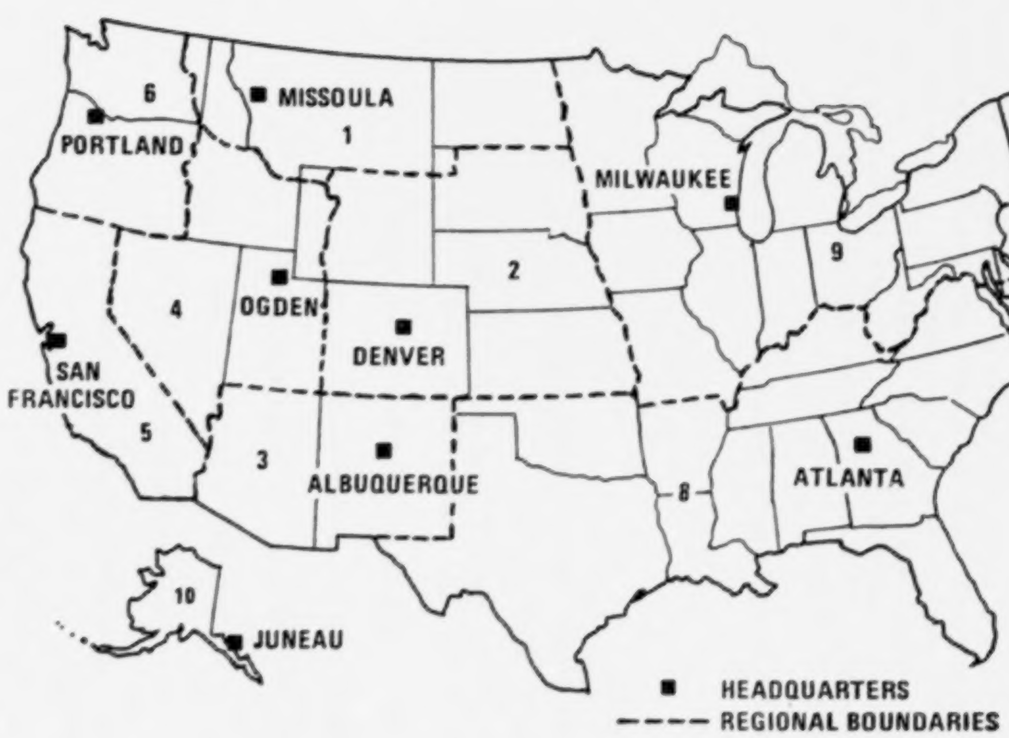
6
PORTLAND
MISSOULA
1
MILWAUKEE
9
2
4
OGDEN
DENVER
SAN FRANCISCO
5
3
ALBUQUERQUE
8
ATLANTA
10
JUNEAU
■ HEADQUARTERS
---- REGIONAL BOUNDARIES

FIGURE 11.1-1. FOREST AREAS AND U. S. FOREST SERVICE REGIONS

11.1.2 Emissions And Controls[1]

It has been hypothesized, but not proven, that the nature and amounts of air pollutant emissions are directly related to the intensity and direction (relative to the wind) of the wildfire, and are indirectly related to the rate at which the fire spreads. The factors that affect the rate of spread are (1) weather (wind velocity, ambient temperature, relative humidity); (2) fuels (fuel type, fuel bed array, moisture content, fuel size); and (3) topography (slope and profile). However, logistical problems (such as size of the burning area) and difficulties in safely situating personnel and equipment close to the fire have prevented the collection of any reliable emissions data on actual wildfires, so that it is not possible to verify or disprove the hypothesis. Therefore, until such measurements are made, the only available information is that obtained from burning experiments in the laboratory. These data, for both emissions and emission factors, are contained in Table 11.1-2. It must be emphasized that the factors presented here are adequate for laboratory scale emissions estimates, but that substantial errors may result if they are used to calculate actual wildfire emissions.

The emissions and emission factors displayed in Table 11.1-2 are calculated using the following formulas:

$$F_i = P_i L \qquad (1)$$

$$E_i = F_i A = P_i LA \qquad (2)$$

where: F_i = Emission factor (mass of pollutant/unit area of forest consumed)

P_i = Yield for pollutant "i" (mass of pollutant/unit mass of forest fuel consumed)

= 8.5 kg/Mg (17 lb/ton) for total particulate

= 70 kg/Mg (140 lb/ton) for carbon monoxide

= 12 kg/Mg (24 lb/ton) for total hydrocarbon (as CH_4)

= 2 kg/Mg (4 lb/ton) for nitrogen oxides (NO_x)

= Negligible for sulfur oxides (SO_x)

L = Fuel loading consumed (mass of forest fuel/unit land area burned)

A = Land area burned

E_i = Total emissions of pollutant "i" (mass pollutant)

For example, suppose that is is necessary to estimate the total particulate emissions from a 10,000 hectare wildfire in the Southern area (Region 8). From Table 11.1-1, it is seen that the average fuel loading is 20 megagrams per hectare (9 tons per acre). Further, the pollutant yield for particulates is 8.5 kilograms per megagram (17 lb/ton). Therefore, the emissions are:

TABLE 11.1-2. EMISSIONS AND EMISSION FACTORS FOR FOREST WILDFIRES

EMISSION FACTOR RATING: D

Georgraphic area	Area consumed by wildfire (hectares)	Wildfire fuel consumption (Mg/hectare)	Emission factors (kg/hectare)				Emissions (Mg)			
			Particulate	Carbon monoxide	Volatile organics[b]	Nitrogen oxides	Particulate	Carbon monoxide	Volatile organics[b]	Nitrogen oxide
Rocky Mountain	313,397	83	706	5,810	996	166	220,907	1,819,237	311,869	51,978
Northern (Region 1)	142,276	135	1,144	9,420	1,620	269	162,268	1,339,283	229,592	38,265
Rocky Mountain (Region 2)	65,882	67	572	4,710	808	135	37,654	310,086	53,157	8,860
Southwestern (Region 3)	83,765	22	191	1,570	269	45	15,957	131,417	22,533	3,735
Intermountain (Region 4)	21,475	40	153	1,260	215	36	3,273	26,953	4,620	770
Pacific	469,906	43	362	2,980	512	85	170,090	1,400,738	240,126	40,021
California (Region 5)	18,997	40	343	2,830	485	91	6,514	53,645	9,196	1,533
Alaska (Region 10)	423,530	36	305	2,510	431	72	129,098	1,063,154	182,255	30,376
Pacific Northwest (Region 6)	27,380	135	1,144	9,420	1,620	269	31,296	257,738	44,183	7,363
Southern	806,289	20	172	1,410	242	40	138,244	1,138,484	195,168	35,528
Southern (Region 8)	806,289	20	172	1,410	242	40	138,244	1,138,484	195,168	35,528
North Central and Eastern	94,191	25	210	1,730	296	49	19,739	162,555	27,867	4,644
(Region 9)	141,238	25	210	1,730	296	49	29,598	243,746	41,785	6,964
Eastern group (With Region 9)	47,046	25	210	1,730	296	49	9,859	81,191	13,918	2,320
Total	1,730,830	38	324	2,670	458	76	560,552	4,616,317	791,369	131,895

[a] Consumption data are for 1971.
[b] Expressed as methane.

$$E = (8.5 \text{ kg/Mg of fuel}) (20 \text{ Mg of fuel hectare}) (10{,}000 \text{ hectares})$$

$$E = 1.700{,}000 \text{ kg} = 1{,}700 \text{ Mg}$$

The most effective method of controlling wildfire emissions is, of course, to prevent the occurrence of wildfires, by various means at the land manager's disposal. A frequently used technique for reducing wildfire occurrence is "prescribed" or "hazard reduction" burning. This type of managed burn involves combustion of litter and underbrush to prevent fuel buildup under controlled conditions, thus reducing the danger of a wildfire. Although some air pollution is generated by this preventive burning, the net amount is believed to be a relatively smaller quantity than that produced by wildfires.

11.1.3 Prescribed Burning[1]

Prescribed burning is a land treatment, used under controlled conditions, to accomplish natural resource management objectives. It is one of several land treatments, used individually or in combination, including chemical and mechanical methods. Prescribed fires are conducted within the limits of a fire plan and prescription which describes both the acceptable range of weather, moisture, fuel and fire behavior parameters and the ignition method to achieve the desired effects. Prescribed fire is a cost effective and ecologically sound tool for forest, range and wetland management. Its use reduces the potential for destructive wildfires and thus maintains long term air quality. Also, the practice removes logging residues, controls insects and disease, improves wildlife habitat and forage production, increases water yield, maintains natural succession of plant communities, and reduces the need for pesticides and herbicides. The major air pollutant concern is the smoke produced.

Smoke from prescribed fires is a complex mixture of carbon, tars, liquids and different gases. This open combustion source produces particles of widely ranging size, depending to some extent on the rate of energy release of the fire. For example, total particulate and particulate less than 2.5 micrometers mean mass cutpoint diameter are produced in different proportions, depending on rates of heat release by the fire.[2] This difference is greatest for the highest intensity fires, and particle volume distribution is bimodal, with peaks near 0.3 micrometers and exceeding 10 micrometers.[3] Particles over about 10 microns, probably of ash and partially burned plant matter, are extrained by the turbulent nature of high intensity fires.

Burning methods differ with fire objectives and with fuel and weather conditions.[4] For example, the various ignition techniques used to burn under standing trees include 1) heading fire, a line of fire that runs with the wind; 2) backing fire, a line of fire that moves into the wind; 3) spot fires, which burn from a number of fires ignited along a line or in a pattern; and 4) flank fire, a line of fire that is lit into the wind, to spread laterally to the direction of the wind. Methods of igniting the fires depend on forest management objectives and the size of the area. Often, on areas of 50 or more acres, helicopters with aerial ignition devices are used to light broadcast burns. Broadcast fires may involve many lines of fire in a pattern that allows the strips of fire to burn together over a sizeable area.

In discussing prescribed burning, the combustion process is divided into preheating, flaming, glowing and smoldering phases. The different phases of combustion greatly affect the amount of emissions produced.[5-7] The preheating phase seldom releases significant quantities of material to the atmosphere. Glowing combustion is usually associated with burning of large concentrations of woody fuels such as logging residue piles. The smoldering combustion phase is a very inefficient and incomplete combustion process that emits pollutants at a much higher ratio to the quantity of fuel consumed than does the flaming combustion of similar materials.

The amount of fuel consumed depends on the moisture content of the fuel.[8-9] For most fuel types, consumption during the smoldering phase is much greatest when the fuel is driest. When lower layers of the fuel are moist, the fire usually is extinguished rapidly.[10]

The major pollutants from wildland burning are particulate, carbon monoxide and volatile organics. Nitrogen oxides are emitted at rates of from 1 to 4 grams per kilogram burned, depending on combustion temperatures. Emissions of sulfur oxides are negligible.[11-12]

Particulate emissions depend on the mix of combustion phase, the rate of energy release, and the type of fuel consumed. All of these elements must be considered in selecting the appropriate emission factor for a given fire and fuel situation. In some cases, models developed by the U. S. Forest Service have been used to predict particulate emission factors and source strength.[13] These models address fire behavior, fuel chemistry, and ignition technique, and they predict the mix of combustion products. There is insufficient knowledge at this time to describe the effect of fuel chemistry on emissions.

Table 11.1-3 presents emission factors from various pollutants, by fire and fuel configuration. Table 11.1-4 gives emission factors for prescribed burning, by geographical area within the United States. Estimates of the percent of total fuel consumed by region were compiled by polling experts from the Forest Service. The emission factors are averages and can vary by as much as 50 percent with fuel and fire conditions. To use these factors, multiply the mass of fuel consumed per hectare by the emission factor for the appropriate fuel type. The mass of fuel consumed by a fire is defined as the available fuel. Local forestry officials often compile information on fuel consumption for prescribed fires and have techniques for estimating fuel consumption under local conditions. The Southern Forestry Smoke Management Guidebook[5] and the Prescribed Fire Smoke Management Guide[15] should be consulted when using these emission factors.

The regional emission factors in Table 11.1-4 should be used only for general planning purposes. Regional averages are based on estimates of the acreage and vegetation type burned and may not reflect prescribed burning activities in a given state. Also, the regions identified are broadly defined, and the mix of vegetation and acres burned within a given state may vary considerably from the regional averages provided. Table 11.1-4 should not be used to develop emission inventories and control strategies.

To develop state emission inventories, the user is strongly urged to contact that state's federal land management agencies and state forestry agencies that conduct prescribed burning to obtain the best information on such activities.

TABLE 11.1-3. EMISSION FACTORS FOR PRESCRIBED BURNING[a]

Fire/fuel configuration	Phase	Pollutant (g/kg)						Fuel mix (%)	Emission Factor Rating
		Particulate			Carbon monoxide	Volatile organics			
		$PM_{2.5}$	PM_{10}	Total		Methane	Nonmethane		
Broadcast logging slash									
Hardwood[b]	F	6	7	13	44	2.1	3.8	33	A
	S	13	14	20	146	8.0	7.7	67	A
	Fire	11	12	18	112	6.1	6.4		A
Conifer									
Short needle[c]	F	7	8	12	72	2.3	2.1	33	A
	S	14	15	19	226	7.2	4.2	67	A
	Fire	12	13	17	175	5.6	3.5		A
Long needle[d]	F	6	6	9	45	1.5	1.7	33	B
	S	16	17	25	166	7.7	5.4	67	B
	Fire	13	13	20	126	5.7	4.2		B
Logging slash debris									
Dozer piled conifer									
No mineral soil[d]	F	4	4	5	28	1.0	–	90	B
	S	6	7	14	116	8.7	–	10	B
	Fire	4	4	6	37	1.8	–		B
10-30% Mineral soil[e]	S	–	–	25	200	–	–		D
25% Organic soil[e]	S	–	–	35	250	–	–		D
Line fire									
Conifer									
Long needle (pine)	Heading[f]	–	40	50	200	–	–		D
	Backing[g]	–	20	20	125	–	–		D
Palmetto/gallberry[g]	Heading	–	15	17	150	–	–		D
	Backing	–	15	15	100	–	–		D
	Fire	–	8 - 22	–	–	–	–		D
Chaparral[h]	Heading	8	9	15	62	2.8	3.5		C
Grasslands[f]	Fire	–	10	10	75	–	–		D

[a] References 7-8. Unless otherwise noted, determined by field testing of fires ≥ 1 acre size. F = flaming. S = smoldering. Fire = weighted average of F and S. Dash = no data.

[b] For PM_{10}, Reference 7. Emission Factor Rating: C.

[c] For PM_{10}, References 3,7. Emission Factor Rating: C.

[d] For PM_{10}, References 3,7. Emission Factor Rating: D.

[e] Reference 12. Determined using laboratory combustion hood.

[f] References 13-14. Determined using laboratory combustion hood.

[g] References 13-14.

[h] Reference 7.

TABLE 11.1-4. EMISSION FACTORS FOR PRESCRIBED BURNING BY U. S. REGION

Regional configuration and fuel type[a]	Percent of fuel[b]	Pollutant[c]			
		Particulate (g/kg)			CO
		$PM_{2.5}$	PM_{10}	PM	
Pacific Northwest					
Logging slash					
Piled slash	42	4	5	6	37
Douglas fir/Western hemlock	24	12	13	17	175
Mixed conifer	19	12	13	17	175
Ponderosa pine	6	13	13	20	126
Hardwood	4	11	12	18	112
Underburning pine	5	30	30	35	163
Average for region	100	9.4	10.3	13.3	111.1
Pacific Southwest					
Sagebrush	35		9	15	62
Chaparral	20	8	9	15	62
Pinyon/Juniper	20		13	17	175
Underburing pine	15		30	35	163
Grassland	10		10	10	75
Average for region	100		13.0	17.8	101.0
Southeast					
Palmetto/gallberry	35		15	16	125
Underburning pine	30		30	35	163
Logging slash	20		13	20	126
Grassland	10		10	10	75
Other	5		17	17	175
Average for region	100		18.8	21.9	134
Rocky Mountain					
Logging slash	50		4	6	37
Underburning pine	20		30	35	163
Grassland	20		10	10	75
Other	10		17	17	175
Average for region	100		11.9	13.7	83.4
North Central and Eastern					
Logging slash	50		13	17	175
Grassland	30		10	10	75
Underburning pine	10		30	35	163
Other	10		17	17	175
Average for region	100		14	16.5	143.8

[a] Regional areas are generalized, e. g., the Pacific Northwest includes Oregon, Washington and parts of Idaho and California. Fuel types generally reflect the ecosystems of a region, but users should seek advice on fuel type mix for a given season of the year. An average factor for Northern California could be more accurately described as chaparral, 25%; underburning pine, 15%; sagebrush, 15%; grassland, 5%; mixed conifer, 25%; and Douglas fir/Western hemlock, 15%. Dash = no data.

[b] Based on the judgment of forestry experts.

[c] Adapted from Table 11.1-3 for the dominant fuel types burned.

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11.2.1 UNPAVED ROADS

11.2.1.1 General

Dust plumes trailing behind vehicles traveling on unpaved roads are a familiar sight in rural areas of the United States. When a vehicle travels an unpaved road, the force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed.

11.2.1.2 Emissions Calculation And Correction Parameters

The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. Also, field investigations have shown that emissions depend on correction parameters (average vehicle speed, average vehicle weight, average number of wheels per vehicle, road surface texture and road surface moisture) that characterize the condition of a particular road and the associated vehicle traffic.[1-4]

Dust emissions from unpaved roads have been found to vary in direct proportion to the fraction of silt (particles smaller than 75 micrometers in diameter) in the road surface materials.[1] The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200 mesh screen, using the ASTM-C-136 method. Table 11.2.1-1 summarizes measured silt values for industrial and rural unpaved roads.

The silt content of a rural dirt road will vary with location, and it should be measured. As a conservative approximation, the silt content of the parent soil in the area can be used. However, tests show that road silt content is normally lower than in the surrounding parent soil, because the fines are continually removed by the vehicle traffic, leaving a higher percentage of coarse particles.

Unpaved roads have a hard, generally nonporous surface that usually dries quickly after a rainfall. The temporary reduction in emissions caused by precipitation may be accounted for by not considering emissions on "wet" days (more than 0.254 millimeters [0.01 inches] of precipitation).

The following empirical expression may be used to estimate the quantity of size specific particulate emissions from an unpaved road, per vehicle kilometer traveled (VKT) or vehicle mile traveled (VMT), with a rating of A:

$$E = k(1.7)\left(\frac{s}{12}\right)\left(\frac{S}{48}\right)\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right) \quad \text{(kg/VKT)}$$

$$E = k(5.9)\left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right) \quad \text{(lb/VMT)}$$

TABLE 11.2.1-1. TYPICAL SILT CONTENT VALUES OF SURFACE MATERIAL ON INDUSTRIAL AND RURAL UNPAVED ROADS[a]

Industry	Road use or surface material	Plant sites	Test samples	Silt (wgt. %)	
				Range	Mean
Copper smelting	Plant road	1	3	15.9 - 19.1	17.0
Iron and steel production	Plant road	9	20	4.0 - 16.0	8.0
Sand and gravel processing	Plant road	1	3	4.1 - 6.0	4.8
Stone quarrying and processing	Plant road	1	5	10.5 - 15.6	14.1
Taconite mining and processing	Haul road	1	12	3.7 - 9.7	5.8
	Service road	1	8	2.4 - 7.1	4.3
Western surface coal mining	Access road	2	2	4.9 - 5.3	5.1
	Haul road	3	21	2.8 - 18	8.4
	Scraper road	3	10	7.2 - 25	17
	Haul road (freshly graded)	2	5	18 - 29	24
Rural roads	Gravel	1	1	NA	5.0
	Dirt	2	5	5.8 - 68	28.5
	Crushed limestone	2	8	7.7 - 13	9.6

[a] References 4-11. NA = Not available.

where: E = emission factor
k = particle size multiplier (dimensionless)
s = silt content of road surface material (%)
S = mean vehicle speed, km/hr (mph)
W = mean vehicle weight, Mg (ton)
w = mean number of wheels
p = number of days with at least 0.254 mm (0.01 in.) of precipitation per year

The particle size multiplier, k, in the equation varies with aerodynamic particle size range as follows:

Aerodynamic Particle Size Multiplier For Equation

$\leq$30 um[a]	$\leq$30 um	$\leq$15 um	$\leq$10 um	$\leq$5um	$\leq$2.5 um
1.0	0.80	0.50	0.36	0.20	0.095

[a] Stokes diameter

The number of wet days per year, p, for the geographical area of interest should be determined from local climatic data. Figure 11.2.1-1 gives the geographical distribution of the mean annual number of wet days per year in the United States.

The equation retains the assigned quality rating, if applied within the ranges of source conditions that were tested in developing the equation, as follows:

Ranges Of Source Conditions For Equation

Road silt content (wgt. %)	Mean vehicle weight		Mean vehicle speed		mean no. of wheels
	Mg	ton	km/hr	mph	
4.3 - 20	2.7 - 142	3 - 157	21 - 64	13 - 40	4 - 13

Also, to retain the quality rating of the equation when addressing a specific unpaved road, it is necessary that reliable correction parameter values be determined for the road in question. The field and laboratory procedures for determining road surface silt content are given in Reference 4. In the event that site specific values for correction parameters cannot be obtained, the appropriate mean values from Table 11.2.1-1 may be used, but the quality rating of the equation is reduced to B.

The equation was developed for calculating annual average emissions, and thus, is to be multiplied by annual vehicle distance traveled (VDT). Annual average values for each of the correction parameters are to be substituted for the equation. Worst case emissions, corresponding to dry road conditions, may be calculated by setting p = 0 in the equation (equivalent to dropping the last

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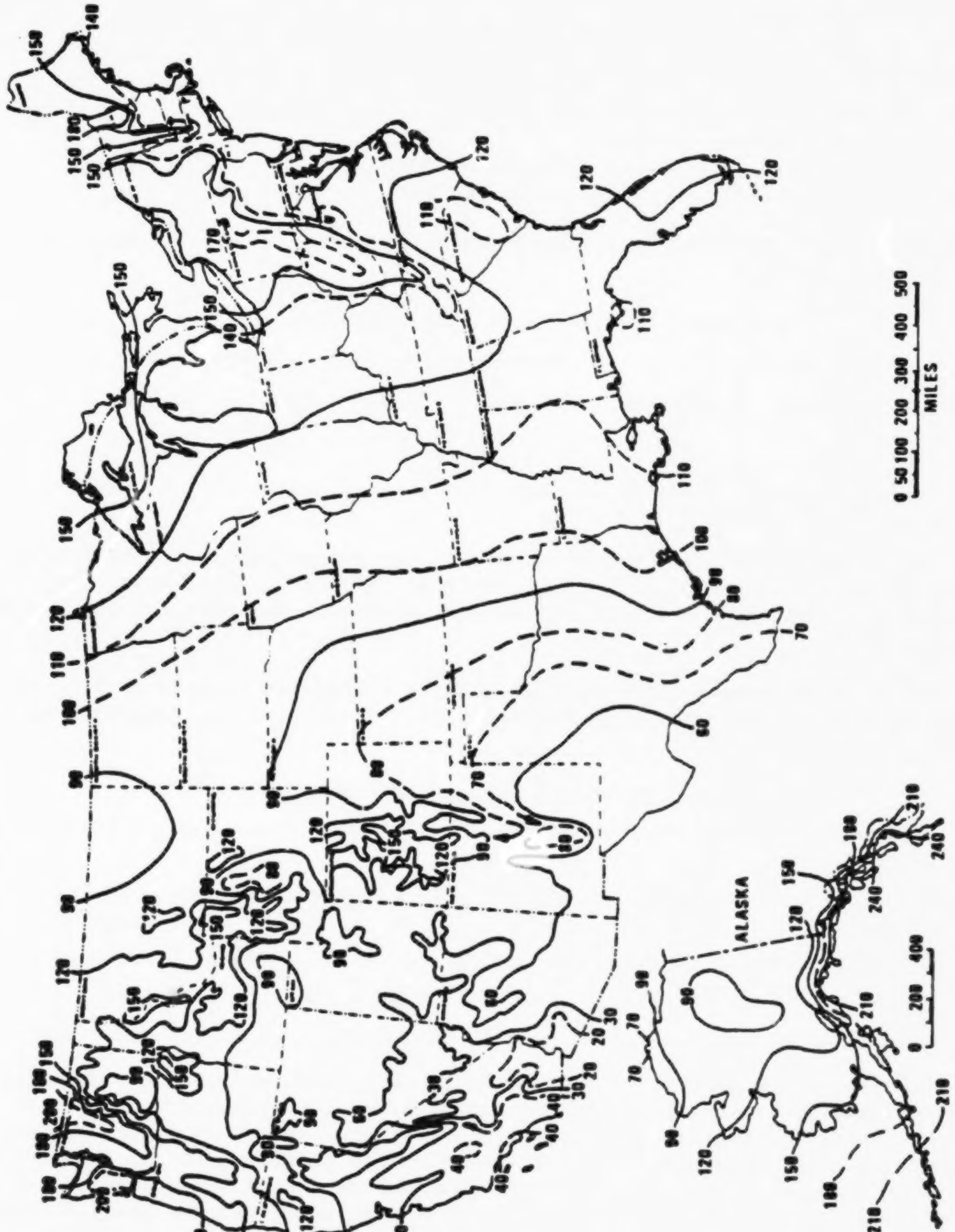
ALASKA
0 50 100 200 300 400 500
MILES
0 200 400

Figure 11.2.1-1. Mean number of days with 0.01 inch or more of precipitation in United States.[10]

term from the equation). A separate set of nonclimatic correction parameters and a higher than normal VDT value may also be justified for the worst case average period (usually 24 hours). Similarly, in using the equation to calculate emissions for a 91 day season of the year, replace the term (365-p)/365 with the term (91-p)/91, and set p equal to the number of wet days in the 91 day period. Also, use appropriate seasonal values for the nonclimatic correction parameters and for VDT.

11.2.1.3 Controls

Common control techniques for unpaved roads are paving, surface treating with penetration chemicals, working into the roadbed of stabilization chemicals, watering, and traffic control regulations. Chemical stabilizers work either by binding the surface material or by enhancing moisture retention. Paving, as a control technique, is often not economically practical. Surface chemical treatment and watering can be accomplished with moderate to low costs, but frequent retreatments are required. Traffic controls, such as speed limits and traffic volume restrictions, provide moderate emission reductions but may be difficult to enforce. The control efficiency obtained by speed reduction can be calculated using the predictive emission factor equation given above.

The control efficiencies achievable by paving can be estimated by comparing emission factors for unpaved and paved road conditions, relative to airborne particle size range of interest. The predictive emission factor equation for paved roads, given in Section 11.2.6, requires estimation of the silt loading on the traveled portion of the paved surface, which in turn depends on whether the pavement is periodically cleaned. Unless curbing is to be installed, the effects of vehicle excursion onto shoulders (berms) also must be taken into account in estimating control efficiency.

The control efficiencies afforded by the periodic use of road stabilization chemicals are much more difficult to estimate. The application parameters which determine control efficiency include dilution ratio, application intensity (mass of diluted chemical per road area) and application frequency. Other factors that affect the performance of chemical stabilizers include vehicle characteristics (e. g., traffic volume, average weight) and road characteristics (e. g., bearing strength).

Besides water, petroleum resin products have historically been the dust suppressants most widely used on industrial unpaved roads. Figure 11.2.1-2 presents a method to estimate average control efficiencies associated with petroleum resins applied to unpaved roads. Several items should be noted:

1. The term "ground inventory" represents the total volume (per unit area) of petroleum resin concentrate (not solution) applied since the start of the dust control season.

2. Because petroleum resin products must be periodically reapplied to unpaved roads, the use of a time-averaged control efficiency value is appropriate. Figure 11.2.1-2 presents control efficiency values averaged over two common application intervals, two weeks and one month. Other application intervals will require interpolation.

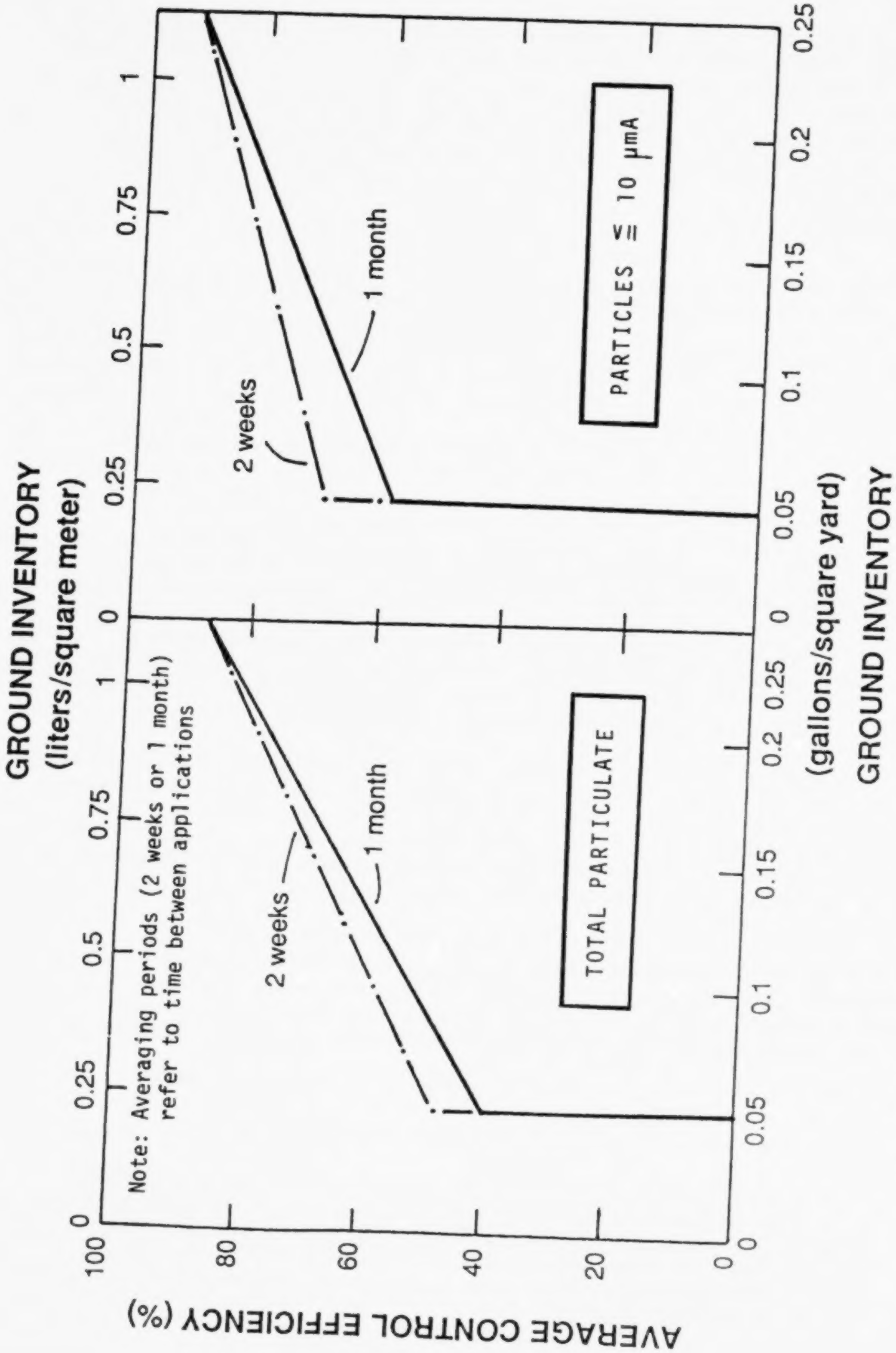

Figure 11.2.1-2. Average control efficiencies over common application intervals.

3. Note that zero efficiency is assigned until the ground inventory reaches 0.2 liters per square meter (0.05 gallons per square yard).

As an example of the use of Figure 11.2.1-2, suppose that the equation has been used to estimate an emission factor of 2.0 kilograms per vehicle kilometer traveled for particles equal to or less than 10 microns from a particular road. Also, suppose that, starting on May 1, the road is treated with 1 liter per square meter of a (1 part petroleum resin to 5 parts water) solution on the first of each month until October. Then, the following average controlled emission factors are found:

Period	Ground Inventory (L/m^2)	Average Control Efficiency[a] (%)	Average Controlled Emission Factor (kg/VKT)
May	0.17	0	2.0
June	0.33	62	0.76
July	0.50	68	0.64
August	0.67	74	0.52
September	0.83	80	0.40

[a] From Figure 11.2.1-2, $\leq$ 10 um. Zero efficiency assigned if ground inventory is less than 0.2 L/m^2 (0.05 gal/yd^2).

Newer dust suppressants have been successful in controlling emissions from unpaved roads. Specific test results for those chemicals, as well as for petroleum resins, are provided in References 14 through 16.

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11.2.3 AGGREGATE HANDLING AND STORAGE PILES

11.2.3.1 General

Inherent in operations that use minerals in aggregate form is the maintenance of outdoor storage piles. Storage piles are usually left uncovered, partially because of the need for frequent material transfer into or out of storage.

Dust emissions occur at several points in the storage cycle, such as during material loading onto the pile, disturbances by strong wind currents, and loadout from the pile. The movement of trucks and loading equipment in the storage pile area is also a substantial source of dust.

11.2.3.2 Emissions And Correction Parameters

The quantity of dust emissions from aggregate storage operations varies with the volume of aggregate passing through the storage cycle. Also, emissions depend on three parameters of the condition of a particular storage pile: age of the pile, moisture content and proportion of aggregate fines.

When freshly processed aggregate is loaded onto a storage pile, its potential for dust emissions is at a maximum. Fines are easily disaggregated and released to the atmosphere upon exposure to air currents, either from aggregate transfer itself or from high winds. As the aggregate weathers, however, potential for dust emissions is greatly reduced. Moisture causes aggregation and cementation of fines to the surfaces of larger particles. Any significant rainfall soaks the interior of the pile, and the drying process is very slow.

Silt (particles equal to or less than 75 microns in diameter) content is determined by measuring the portion of dry aggregate material that passes through a 200 mesh screen, using ASTM-C-136 method. Table 11.2.3-1 summarizes measured silt and moisture values for industrial aggregate materials.

11.2.3.3 Predictive Emission Factor Equations

Total dust emissions from aggregate storage piles are contributions of several distinct source activities within the storage cycle:

1. Loading of aggregate onto storage piles (batch or continuous drop operations).
2. Equipment traffic in storage area.
3. Wind erosion of pile surfaces and ground areas around piles.
4. Loadout of aggregate for shipment or for return to the process stream (batch or continuous drop operations).

Adding aggregate material to a storage pile or removing it both usually involve dropping the material onto a receiving surface. Truck dumping on the pile or loading out from the pile to a truck with a front end loader are examples of batch drop operations. Adding material to the pile by a conveyor stacker is an example of a continuous drop operation.

TABLE 11.2.3-1. TYPICAL SILT AND MOISTURE CONTENT VALUES OF MATERIALS AT VARIOUS INDUSTRIES

Industry	Material	Silt (%)			Moisture (%)		
		No. of test samplers	Range	Mean	No. of test samplers	Range	Mean
Iron and steel production[a]	Pellet ore	10	1.4 - 13	4.9	8	0.64 - 3.5	2.1
	Lump ore	9	2.8 - 19	9.5	6	1.6 - 8.1	5.4
	Coal	7	2 - 7.7	5	6	2.8 - 11	4.8
	Slag	3	3 - 7.3	5.3	3	0.25 - 2.2	0.92
	Flue dust	2	14 - 23	18.0	0	NA	NA
	Coke breeze	1		5.4	1		6.4
	Blended ore	1		15.0	1		6.6
	Sinter	1		0.7	0	NA	NA
	Limestone	1		0.4	0	NA	NA
Stone quarrying and processing[b]	Crushed limestone	2	1.3 - 1.9	1.6	2	0.3 - 1.1	0.7
Taconite mining and processing[c]	Pellets	9	2.2 - 5.4	3.4	7	0.05 - 2.3	0.9
	Tailings	2	NA	11.0	1		0.35
Western surface coal mining[d]	Coal	15	3.4 - 16	6.2	7	2.8 - 20	6.9
	Overburden	15	3.8 - 15	7.5	0	NA	NA
	Exposed ground	3	5.1 - 21	15.0	3	0.8 - 6.4	3.4
Coal fired power generation[e]	Coal	60	0.6 - 4.8	2.2	59	2.7 - 7.4	4.5

[a] References 2-5. NA = not applicable.

[b] Reference 1.

[c] Reference 6.

[d] Reference 7.

[e] Reference 8. Values reflect "as received" conditions of a single power plant.

The quantity of particulate emissions generated by either type of drop operation, per ton of material transferred, may be estimated, with a rating of A, using the following empirical expression[2]:

$$E = k(0.0016)\,\frac{\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}}\ \text{(kg/Mg)}$$

$$E = k(0.0032)\,\frac{\left(\frac{U}{5}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}}\ \text{(lb/ton)}$$

where: E = emission factor
k = particle size multiplier (dimensionless)
U = mean wind speed, m/s (mph)
M = material moisture content (%)

The particle size multiplier, k, varies with aerodynamic particle diameter, as shown in Table 11.2.3-2.

TABLE 11.2.3-2. AERODYNAMIC PARTICLE SIZE MULTIPLIER (k)

<30 um	<15 um	<10 um	<5 um	<2.5 um
0.74	0.48	0.35	0.20	0.11

The equation retains the assigned quality rating if applied within the ranges of source conditions that were tested in developing the equation, as given in Table 11.2.3-3. Note that silt content is included in Table 11.2.3-3, even though silt content does not appear as a correction parameter in the equation. While it is reasonable to expect that silt content and emission factors are interrelated, no significant correlation between the two was found during the derivation of the equation, probably because most tests with high silt contents were conducted under lower winds, and vice versa. It is recommended that estimates from the equation be reduced one quality rating level, if the silt content used in a particular application falls outside the range given in Table 11.2.3-3.

TABLE 11.2.3-3. RANGES OF SOURCE CONDITIONS FOR EQUATION 1

Silt Content	Moisture Content	Wind Speed (m/s)	Wind Speed (mph)
0.44 - 19	0.25 - 4.8	0.6 - 6.7	1.3 - 15

Also, to retain the equation's quality rating when applied to a specific facility, it is necessary that reliable correction parameters be determined for the specific sources of interest. The field and laboratory procedures for aggregate sampling are given in Reference 3. In the event that site specific values for correction parameters cannot be obtained, the appropriate mean values from Table 11.2.3-1 may be used, but, in that case, the quality rating of the equation is reduced by one level.

For emissions from equipment traffic (trucks, front end loaders, dozers, etc.) traveling between or on piles, it is recommended that the equations for vehicle traffic on unpaved surfaces be used (see Section 11.2.1). For vehicle travel between storage piles, the silt value(s) for the areas among the piles (which may differ from the silt values for the stored materials) should be used.

Worst case emissions from storage pile areas occur under dry windy conditions. Worst case emissions from materials handling operations may be calculated by substituting into the equation appropriate values for aggregate material moisture content and for anticipated wind speeds during the worst case averaging period, usually 24 hours. The treatment of dry conditions for vehicle traffic (Section 11.2.1), centering on parameter p, follows the methodology described in Section 11.2.1. Also, a separate set of nonclimatic correction parameters and source extent values corresponding to higher than normal storage pile activity may be justified for the worst case averaging period.

11.2.3.4 Controls

Watering and chemical wetting agents are the principal means for control of aggregate storage pile emissions. Enclosure or covering of inactive piles to reduce wind erosion can also reduce emissions. Watering is useful mainly to reduce emissions from vehicle traffic in the storage pile area. Watering of the storage piles themselves typically has only a very temporary slight effect on total emissions. A much more effective technique is to apply chemical wetting agents for better wetting of fines and longer retention of the moisture film. Continuous chemical treatment of material loaded onto piles, coupled with watering or treatment of roadways, can reduce total particulate emissions from aggregate storage operations by up to 90 percent.[9]

References for Section 11.2.3

1. C. Cowherd, Jr., et al., Development Of Emission Factors For Fugitive Dust Sources, EPA-450/3-74-037, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.

2. R. Bohn, et al., Fugitive Emissions From Integrated Iron And Steel Plants, EPA-600/2-78-050, U. S. Environmental Protection Agency, Cincinnati, OH, March 1978.

3. C. Cowherd, Jr., et al., Iron And Steel Plant Open Dust Source Fugitive Emission Evaluation, EPA-600/2-79-103, U. S. Environmental Protection Agency, Cincinnati, OH, May 1979.

4. R. Bohn, Evaluation Of Open Dust Sources In The Vicinity Of Buffalo, New York, EPA Contract No. 68-02-2545, Midwest Research Institute, Kansas City, MO, March 1979.

5. C. Cowherd, Jr., and T. Cuscino, Jr., Fugitive Emissions Evaluation, MRI-4343-L, Midwest Research Institute, Kansas City, MO, February 1977.

6. T. Cuscino, et al., Taconite Mining Fugitive Emissions Study, Minnesota Pollution Control Agency, Roseville, MN, June 1979.

7. K. Axetell and C. Cowherd, Jr., Improved Emission Factors For Fugitive Dust From Western Surface Coal Mining Sources, 2 Volumes, EPA Contract No. 68-03-2924, PEI, Inc., Kansas City, MO, July 1981.

8. E. T. Brookman, et al., Determination of Fugitive Coal Dust Emissions From Rotary Railcar Dumping, 1956-L81-00, TRC, Hartford, CT, May 1984.

9. G. A. Jutze, et al., Investigation Of Fugitive Dust Sources Emissions And Control, EPA-450/3-74-036a, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.

11.2.6 INDUSTRIAL PAVED ROADS

11.2.6.1 General

Various field studies have indicated that dust emissions from industrial paved roads are a major component of atmospheric particulate matter in the vicinity of industrial operations. Industrial traffic dust has been found to consist primarily of mineral matter, mostly tracked or deposited onto the roadway by vehicle traffic itself, when vehicles enter from an unpaved area or travel on the shoulder of the road, or when material is spilled onto the paved surface from open truck bodies.

11.2.6.2 Emissions And Correction Parameters[1-2]

The quantity of dust emissions from a given segment of paved road varies linearly with the volume of traffic. In addition, field investigations have shown that emissions depend on correction parameters (road surface silt content, surface dust loading and average vehicle weight) of a particular road and associated vehicle traffic.

Dust emissions from industrial paved roads have been found to vary in direct proportion to the fraction of silt (particles equal to or less than 75 microns in diameter) in the road surface material. The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200 mesh screen, using the ASTM-C-136 method. In addition, it has also been found that emissions vary in direct proportion to the surface dust loading. The road surface dust loading is that loose material which can be collected by broom sweeping and vacuuming of the traveled portion of the paved road. Table 11.2.6-1 summarizes measured silt and loading values for industrial paved roads.

11.2.6.3 Predictive Emission Factor Equations

The quantity of total suspended particulate emissions generated by vehicle traffic on dry industrial paved roads, per vehicle kilometer traveled (VKT) or vehicle mile traveled (VMT), may be estimated with a rating of B or D (see below), using the following empirical expression[2]:

$$E = 0.022\ I \left(\frac{4}{n}\right)\left(\frac{s}{10}\right)\left(\frac{L}{280}\right)\left(\frac{W}{2.7}\right)^{0.7} \quad \text{(kg/VKT)} \qquad (1)$$

$$E = 0.077\ I \left(\frac{4}{n}\right)\left(\frac{s}{10}\right)\left(\frac{L}{1000}\right)\left(\frac{W}{3}\right)^{0.7} \quad \text{(lb/VMT)}$$

where: E = emission factor
I = industrial augmentation factor (dimensionless) (see below)
n = number of traffic lanes
s = surface material silt content (%)
L = surface dust loading, kg/km (lb/mile) (see below)
W = average vehicle weight, Mg (ton)

TABLE 11.2.6-1. TYPICAL SILT CONTENT AND LOADING VALUES FOR PAVED ROADS AT INDUSTRIAL FACILITIES[a]

Industry	No. of sites	No. of samples	Silt (wgt. %)		No. of travel lanes	Total loading x 10^{-3}			Silt loading (g/m^2)	
			Range	Mean		Range	Mean	Units[b]	Range	Mean
Copper smelting	1	3	15.4 - 21.7	19.0	2	12.9 - 19.5 45.8 - 69.2	15.9 55.4	kg/km lb/mi	188 - 400	292
Iron and steel production	6	20	1.1 - 35.7	12.5	2	0.006 - 4.77 0.020 - 16.9	0.495 1.75	kg/km lb/mi	0.09 - 79	12
Asphalt batching	1	3	2.6 - 4.6	3.3	1	12.1 - 18.0 43.0 - 64.0	14.9 52.8	kg/km lb/mi	76 - 193	120
Concrete batching	1	3	5.2 - 6.0	5.5	2	1.4 - 1.8 5.0 - 6.4	1.7 5.9	kg/km lb/mi	11 - 12	12
Sand and gravel processing	1	3	6.4 - 7.9	7.1	1	2.8 - 5.5 9.9 - 19.4	3.8 13.3	kg/km lb/mi	53 - 95	70

[a] References 1-5.

[b] Multiply entries by 1,000 to obtain stated units.

The industrial road augmentation factor (I) in Equation 1 takes into account higher emissions from industrial roads than from urban roads. I = 7.0 for a paved industrial roadway which traffic enters from unpaved areas. I = 3.5 for an industrial roadway with unpaved shoulders where 20 percent of the vehicles are forced to travel temporarily with one set of wheels on the shoulder. I = 1.0 for cases in which traffic travels only on paved areas. A value between 1.0 and 7.0 which best represents conditions for paved roads at a certain industrial facility should be used for I in the equation.

The equation retains the quality rating of B if applied to vehicles traveling entirely on paved surfaces (I = 1.0) and if applied within the range of source conditions that were tested in developing the equation as follows:

Silt content (%)	Surface loading		No. of lanes	Vehicle weight	
	kg/km	lb/mile		Mg	tons
5.1 - 92	42.0 - 2000	149 - 7100	2 - 4	2.7 - 12	3 - 13

If I is less than 1.0, the rating of the equation drops to D, because of the subjectivity in the guidelines for estimating I.

The quantity of particle emissions in the finer size ranges generated by traffic consisting predominately of medium and heavy duty vehicles on dry industrial paved roads, per vehicle unit of travel, may be estimated, with a rating of A, using the equation:

$$E = k \left(\frac{sL}{12}\right)^{0.3} \quad (\text{kg/VKT}) \qquad (2)$$

$$E = k(3.5) \left(\frac{sL}{0.35}\right)^{0.3} \quad (\text{lb/VMT})$$

where: E = emission factor
sL = road surface silt loading, g/m^2 (oz/yd^2)

The particle size multiplier (k) above varies with aerodynamic size range as follows:

Aerodynamic Particle Size Multiplier (k) For Equation 2 (Dimensionless)		
$\leq$15 um	$\leq$10 um	$\leq$2.5 um
0.28	0.22	0.081

To determine particulate emissions for a specific particle size range, use the appropriate value of k above.

The equation retains the quality rating of A, if applied within the range of source conditions that were tested in developing the equation as follows:

silt loading, 2 - 240 g/m^2 (0.06 - 7.1 oz/yd^2)

mean vehicle weight, 6 - 42 Mg (7 - 46 tons)

The following single valued emission factors[6] may be used in lieu of Equation 2 to estimate particle emissions in the finer size ranges generated by light duty vehicles on dry, heavily loaded industrial roads, with a rating of C:

Emission Factors For Light Duty Vehicles On Heavily Loaded Roads	
$\leq$15 um	$\leq$10 um
0.12 kg/VKT (0.41 lb/VMT)	0.093 kg/VKT (0.33 lb/VMT)

These emission factors retain the assigned quality rating, if applied within the range of source conditions that were tested in developing the factors, as follows:

silt loading, 15 - 400 g/m^2 (0.44 - 12 oz/yd^2)

mean vehicle weight, $\leq$4 Mg ($\leq$4 tons)

Also, to retain the quality ratings of Equations 1 and 2 when applied to a specific industrial paved road, it is necessary that reliable correction parameter values for the specific road in question be determined. The field and laboratory procedures for determining surface material silt content and surface dust loading are given in Reference 2. In the event that site specific values for correction parameters cannot be obtained, the appropriate mean values from Table 11.2.6-1 may be used, but the quality ratings of the equation should be reduced by one level.

11.2.6.4 Controls

Common control techniques for industrial paved roads are broom sweeping, vacuum sweeping and water flushing, used alone or in combination. All of these techniques work by reducing the silt loading on the traveled portions of the road. As indicated by a comparison of Equations 1 and 2, fine particle emissions are less sensitive to the value of silt loading than are total suspend particulate emissions. Consistent with this, control techniques are generally less effective for the finer particle sizes.[4] The exception is water flushing, which appears preferentially to remove (or agglomerate) fine particles from the paved road surface. Broom sweeping is generally regarded as the least effective of the common control techniques, because the mechanical sweeping process is inefficient in removing silt from the road surface.

Although there are relatively few quantitative data on emissions from controlled paved roads, those that are available indicate that adequate estimates generally may be obtained by substituting controlled loading values into Equations 1 and 2. The major exception to this is water flushing combined with broom sweeping. In that case, the equations tend to overestimate emissions substantially (by an average factor of 4 or more).

On a paved road with moderate traffic (500 vehicles per day), to achieve control efficiencies on the order of 50 percent, requires cleaning of the surface at least twice per week.[4] This is because of the characteristically rapid buildup of road surface material from spillage and the tracking and deposition of material from adjacent unpaved surfaces, including the shoulders (berms) of the paved road. Because industrial paved roads usually do not have curbs, it is important that the width of the paved road surface be sufficient for vehicles to pass without excursion onto unpaved shoulders. Equation 1 indicates that eliminating vehicle travel on unpaved or untreated shoulders would effect a major reduction in particulate emissions. An even greater effect, by a factor of 7, would result from preventing travel from unpaved roads or parking lots onto the paved road of interest.

References for Section 11.2.6

1. R. Bohn, et al., Fugitive Emissions From Integrated Oron And Steel Plants, EPA-600/2-78-050, U. S. Environmental Protection Agency, Cincinnati, OH, March 1978.

2. C. Cowherd, Jr., et al., Iron And Steel Plant Open Dust Source Fugitive Emission Evaluation, EPA-600/2-79-103, U. S. Environmental Protection Agency, Cincinnati, OH, May 1979.

3. R. Bohn, Evaluation Of Open Dust Sources In The Vicinity Of Buffalo, New York, EPA Contract No. 68-02-2545, Midwest Research Institute, Kansas City, MO, March, 1979.

4. T. Cuscino, Jr., et al., Iron And Steel Plant Open Source Fugitive Emission Control Evaluation, EPA-600/2-83-110, U. S. Environmental Protection Agency, Cincinnati, OH, October 1983.

5. J. Patrick Reider, Size Specific Particulate Emission Factors For Uncontrolled Industrial And Rural Roads, EPA Contract No. 68-02-3158, Midwest Research Institute, Kansas City, MO, September 1983.

6. C. Cowherd, Jr., and P. Englehart, Size Specific Particulate Emission Factors For Industrial And Rural Roads, EPA-600/7-85-038, U. S. Environmental Protection Agency, Cincinnati, OH, September 1985.

11.2.7 INDUSTRIAL WIND EROSION

11.2.7.1 General[1-3]

Dust emissions may be generated by wind erosion of open aggregate storage piles and exposed areas within an industrial facility. These sources typically are characterized by nonhomogeneous surfaces impregnated with nonerodible elements (particles larger than approximately 1 cm in diameter). Field testing of coal piles and other exposed materials using a portable wind tunnel has shown that (a) threshold wind speeds exceed 5 m/s (11 mph) at 15 cm above the surface or 10 m/s (22 mph) at 7 m above the surface, and (b) particulate emission rates tend to decay rapidly (half life of a few minutes) during an erosion event. In other words, these aggregate material surfaces are characterized by finite availability of erodible material (mass/area) referred to as the erosion potential. Any natural crusting of the surface binds the erodible material, thereby reducing the erosion potential.

11.2.7.2 Emissions And Correction Parameters

If typical values for threshold wind speed at 15 cm are corrected to typical wind sensor height (7-10 m), the resulting values exceed the upper extremes of hourly mean wind speeds observed in most areas of the country. In other words, mean atmospheric wind speeds are not sufficient to sustain wind erosion from flat surfaces of the type tested. However, wind gusts may quickly deplete a substantial portion of the erosion potential. Because erosion potential has been found to increase rapidly with increasing wind speed, estimated emissions should be related to the gusts of highest magnitude.

The routinely measured meteorological variable which best reflects the magnitude of wind gusts is the fastest mile. This quantity represents the wind speed corresponding to the whole mile of wind movement which has passed by the 1 mile contact anemometer in the least amount of time. Daily measurements of the fastest mile are presented in the monthly Local Climatological Data (LCD) summaries. The duration of the fastest mile, typically about 2 min (for a fastest mile of 30 mph), matches well with the half life of the erosion process, which ranges between 1 and 4 min. It should be noted, however, that peak winds can significantly exceed the daily fastest mile.

The wind speed profile in the surface boundary layer is found to follow a logarithmic distribution:

$$u(z) = \frac{u^*}{0.4} \ln \frac{z}{z_0} \quad (z > z_0) \qquad (1)$$

where u = wind speed, cm/sec
u^* = friction velocity, cm/sec
z = height above test surface, cm
z_0 = roughness height, cm
0.4 = von Karman's constant, dimensionless

The friction velocity (u^*) is a measure of wind shear stress on the erodible surface, as determined from the slope of the logarithmic velocity profile. The roughness height (z_0) is a measure of the roughness of the exposed surface as determined from the y intercept of the velocity profile, i.e., the height at which the wind speed is zero. These parameters are illustrated in Figure 11.2.7-1 for a roughness height of 0.1 cm.

Emissions generated by wind erosion are also dependent on the frequency of disturbance of the erodible surface because each time that a surface is disturbed, its erosion potential is restored. A disturbance is defined as an action which results in the exposure of fresh surface material. On a storage pile, this would occur whenever aggregate material is either added to or removed from the old surface. A disturbance of an exposed area may also result from the turning of surface material to a depth exceeding the size of the largest pieces of material present.

11.2.7.3 Predictive Emission Factor Equation[4]

The emission factor for wind generated particulate emissions from mixtures of erodible and nonerodible surface material subject to disturbance may be expressed in units of g/m^2-yr as follows:

$$\text{Emission factor} = k \sum_{i=1}^{N} P_i \qquad (2)$$

where k = particle size multiplier
N = number of disturbances per year
Pi = erosion potential corresponding to the observed (or probable) fastest mile of wind for the ith period between disturbances, g/m^2

The particle size multiplier (k) for Equation 2 varies with aerodynamic particle size, as follows:

AERODYNAMIC PARTICLE SIZE MULTIPLIERS FOR EQUATION 2

<30 um	<15 um	<10 um	<2.5 um
1.0	0.6	0.5	0.2

This distribution of particle size within the <30um fraction is comparable to the distributions reported for other fugitive dust sources where wind speed is a factor. This is illustrated, for example, in the distributions for batch and continuous drop operations encompassing a number of test aggregate materials (see Section 11.2.3).

In calculating emission factors, each area of an erodible surface that is subject to a different frequency of disturbance should be treated separately. For a surface disturbed daily, N = 365/yr, and for a surface disturbance once every 6 months, N = 2/yr.

Equations 2 and 3 apply only to dry, exposed materials with limited erosion potential. The resulting calculation is valid only for a time period as long or longer than the period between disturbances. Calculated emissions represent intermittent events and should not be input directly into dispersion models that assume steady state emission rates.

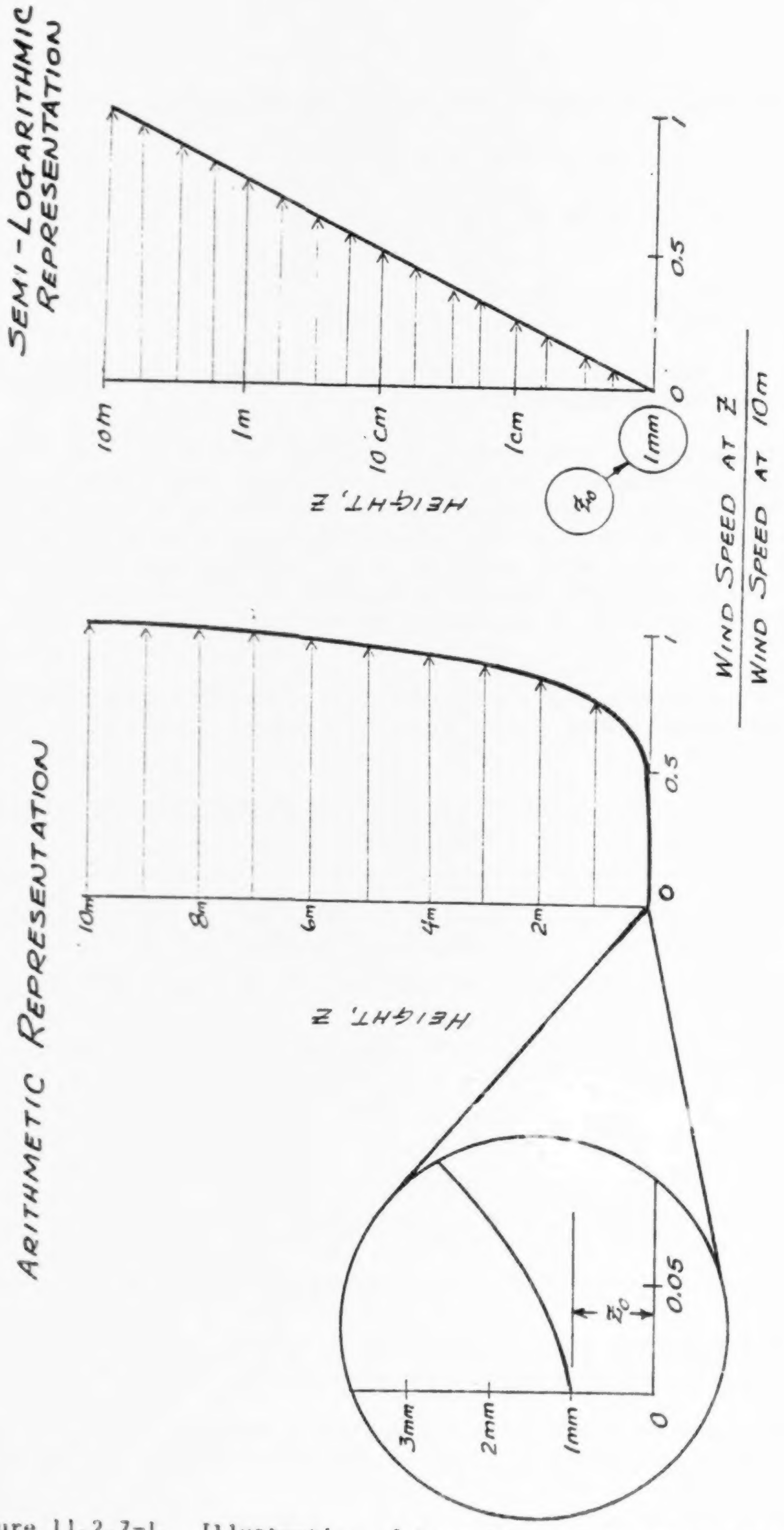


Figure 11.2.7-1. Illustration of logarithmic velocity profile.

The erosion potential function for a dry, exposed surface is:

$$P = 58\ (u^* - u^*_t)2\ 25\ (u^* - u^*_t)$$

$$P = 0 \text{ for } u^* \leq u^*_t \qquad (3)$$

where u^* = friction velocity (m/s)
u_t = threshold friction velocity (m/s)

Because of the nonlinear form of the erosion potential function, each erosion event must be treated separately.

For uncrusted surfaces, the threshold friction velocity is best estimated from the dry aggregate structure of the soil. A simple hand sieving test of surface soil (adapted from a laboratory procedure published by W. S. Chepil) can be used to determine the mode of the surface aggregate size distribution by inspection of relative sieve catch amounts, following the procedure described below. Alternatively, the threshold friction velocity for erosion can be determined from the mode of the aggregate size distribution, as described by Gillette.[5-6]

Threshold friction velocities for several surface types have been determined by field measurements with a portable wind tunnel. These values are presented in Table 11.2.7-1.

TABLE 11.2.7-1. FIELD PROCEDURE FOR DETERMINTION OF THRESHOLD FRICTION VELOCITY

Tyler sieve no.	Opening (mm)	Midpoint (mm)	u^*_t (cm/sec)
5	4		
		3	100
9	2		
		1.5	72
16	1		
		0.75	58
32	0.5		
		0.375	43
60	0.25		

FIELD PROCEDURE FOR DETERMINATION OF THRESHOLD FRICTION VELOCITY

(from a 1952 laboratory procedure published by W. S. Chepil)

1. Prepare a nest of sieves with the following openings: 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm. Place a collector pan below th crhhrj·ftaga *5M36 jj¶M

2. Collect a sample representing the surface layer of loose particles (approximately 1 cm in depth, for an encrusted surface), removing any rocks

larger than about 1 cm in average physical diameter. The area to be sampled should be not less than 30 cm.

3. Pour the sample into the top sieve (4 mm opening), and place a lid on the top.

4. Move the covered sieve/pan unit by hand, using a broad circular arm motion in the horizontal plane. Complete 20 circular movements at a speed just necessary to achieve some relative horizontal motion between the sieve and the particles.

5. Inspect the relative quantities of catch within each sieve, and determine where the mode in the aggregate size distribution lies, i. e., between the opening size of the sieve with the largest catch and the opening size of the next largest sieve.

6. Determine the threshold friction velocity from Figure 1.

The fastest mile of wind for the periods between disturbances may be obtained from the monthly LCD summaries for the nearest reporting weather station that is representative of the site in question.[7] These summaries report actual fastest mile values for each day of a given month. Because the erosion potential is a highly nonlinear function of the fastest mile, mean values of the fastest mile are inappropriate. The anemometer heights of reporting weather stations are found in Reference 8, and should be corrected to a 10 m reference height using Equation 1.

TABLE 11.2.7-2. THRESHOLD FRICTION VELOCITIES

Material	Threshold friction velocity (m/s)	Roughness height (cm)	Threshold wind velocity at 10 m (m/s) z_0 = Actual	 z_0 = 0.5 cm	Ref.
Overburden[a]	1.02	0.3	21	19	2
Scoria (roadbed material)[a]	1.33	0.3	27	25	2
Ground coal[a] (surrounding coal pile)	0.55	0.01	16	10	2
Uncrusted coal pile[a]	1.12	0.3	23	21	2
Scraper tracks on coal pile[a,b]	0.62	0.06	15	12	2
Fine coal dust on concrete pad[c]	0.54	0.2	11	10	3

[a] Western surface coal mine.
[b] Lightly crusted.
[c] Eastern power plant.

To convert the fastest mile of wind (u^+) from a reference anemometer height of 10 m to the equivalent friction velocity (u^*), the logarithmic wind speed profile may be used to yield the following equation:

$$u^* = 0.053\ u^+_{10} \qquad (4)$$

where u^* = friction velocity (m/s)

u^+_{10} = fastest mile of reference anemometer for period between disturbances (m/s)

This assumes a typical roughness height of 0.5 cm for open terrain. Equation 4 is restricted to large relatively flat piles or exposed areas with little penetration into the surface wind layer.

If the pile significantly penetrates the surface wind layer (i.e., with a height-to-base ratio exceeding 0.2), it is necessary to divide the pile area into subareas representing different degrees of exposure to wind. The results of physical modeling show that the frontal face of an elevated pile is exposed to wind speeds of the same order as the approach wind speed at the top of the pile.

For two representative pile shapes (conical and oval with flattop, 37 degree side slope), the ratios of surface wind speed (u_s) to approach wind speed (u_r) have been derived from wind tunnel studies.[9] The results are shown in Figure 11.2.7-2 corresponding to an actual pile height of 11 m, a reference (upwind) anemometer height of 10 m, and a pile surface roughness height (z_o) of 0.5 cm. The measured surface winds correspond to a height of 25 cm above the surface. The area fraction within each contour pair is specified in Table 11.2.7-3.

The profiles of u_s/u_r in Figure 11.2.7-2 can be used to estimate the surface friction velocity distribution around similarly shaped piles, using the following procedure:

1. Correct the fastest mile value (u^+) for the period of interest from the anemometer height (z) to a reference height of 10 m (u^+_{10}) using a variation of Equation 1:

$$u^+_{10} = u^+ \frac{\ln\ (10/0.005)}{\ln\ (z/0.005)} \qquad (5)$$

where a typical roughness height of 0.5 cm (0.005 m) has been assumed. If a site specific roughness height is available, it should be used.

2. Use the appropriate part of Figure 11.2.7-2 based on the pile shape and orientation to the fastest mile of wind, to obtain the corresponding surface wind speed distribution (u^+_s):

$$u^+_s = \left(\frac{u_s}{u_r}\right) u^+_{10} \qquad (6)$$

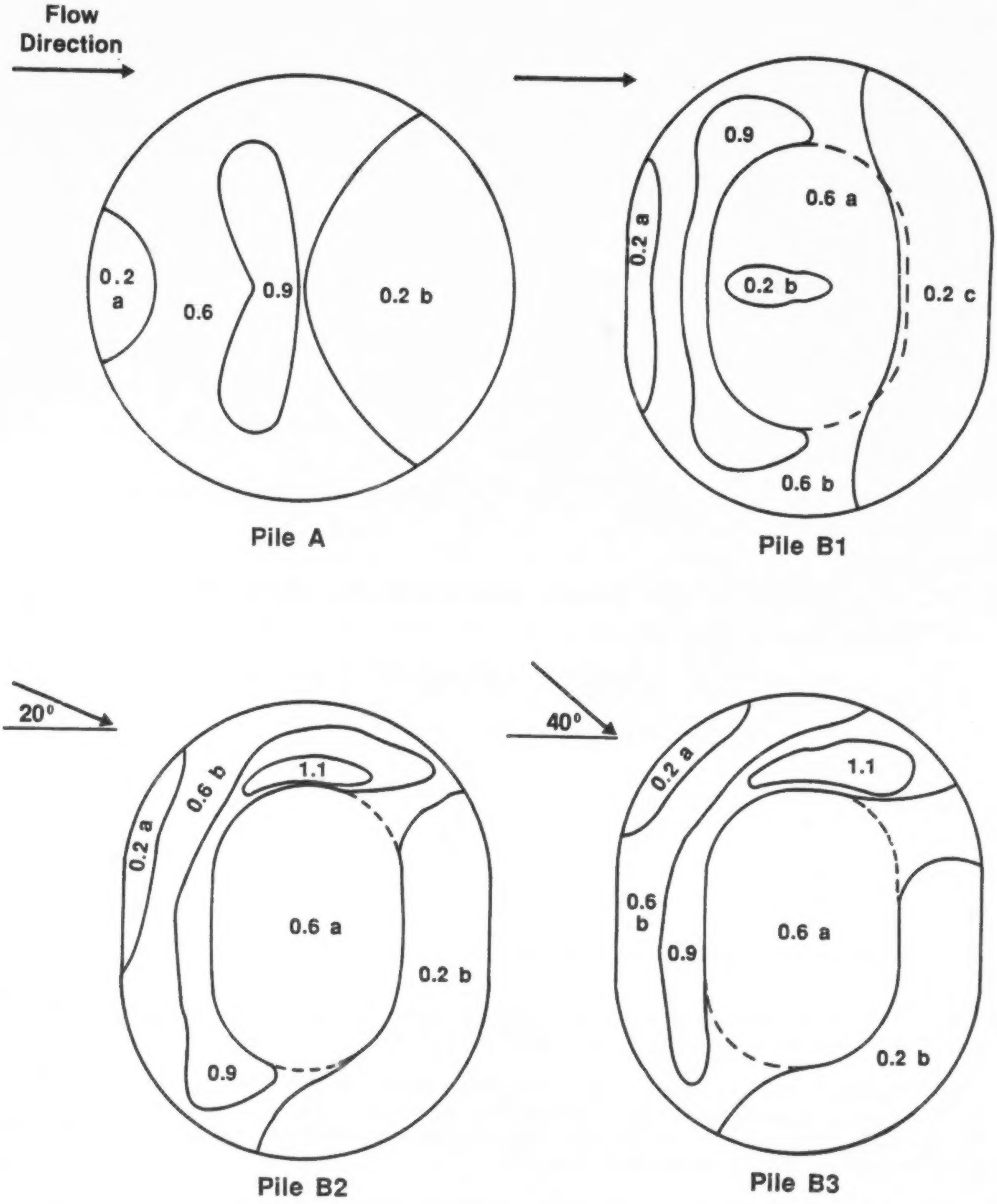

Flow Direction
0.2 a
0.6
0.9
0.2 b
Pile A
0.9
0.6 a
0.2 a
0.2 b
0.2 c
0.6 b
Pile B1
20°
0.2 a
0.6 b
1.1
0.6 a
0.2 b
0.9
Pile B2
40°
0.2 a
1.1
0.6 b
0.9
0.6 a
0.2 b
Pile B3

Figure 11.2.7-2. Contours of Normalized Surface Wind Speeds, u_s/u_r

3. For any subarea of the pile surface having a narrow range of surface wind speed, use a variation of Equation 1 to calculate the equivalent friction velocity (u*):

$$u^* = \frac{0.4\ u^+_s}{\ln \frac{25}{0.5}} = 0.10\ u^+_s$$

From this point on, the procedure is identical to that used for a flat pile, as described above.

Implementation of the above procedure is carried out in the following steps:

1. Determine threshold friction velocity for erodible material of interest (see Table 11.2.7-2 or determine from mode of aggregate size distribution).

2. Divide the exposed surface area into subareas of constant frequency of disturbance (N).

TABLE 11.2.7-2. SUBAREA DISTRIBUTION FOR REGIMES OF u_s/u_r

Pile subarea	Percent of pile surface area (Figure 11.2.7-2)			
	Pile A	Pile B1	Pile B2	Pile B3
0.2a	5	5	3	3
0.2b	35	2	28	25
0.2c	-	29	-	-
0.6a	48	26	29	28
0.6b	-	24	22	26
0.9	12	14	15	14
1.1	-	-	3	4

3. Tabulate fastest mile values (u+) for each frequency of disturbance and correct them to 10 m (u^+_{10}) using Equation 5.

4. Convert fastest mile values (u^+_{10}) to equivalent friction velocities (u*), taking into account (a) the uniform wind exposure of nonelevated surfaces, using Equation 4, or (b) the nonuniform wind exposure of elevated surfaces (piles), using Equations 6 and 7.

5. For elevated surfaces (piles), subdivide areas of constant N into subareas of constant u* (i.e., within the isopleth values of u_s/u_r in Figure 11.2.7-2 and Table 11.2.7-3) and determine the size of each subarea.

6. Treating each subarea (of constant N and u*) as a separate source, calculate the erosion potential (P_i) for each period between disturbances using Equation 3 and the emission factor using Equation 2.

7. Multiply the resulting emission factor for each subarea by the size of the subarea, and add the emission contributions of all subareas. Note that the highest 24-hr emissions would be expected to occur on the windiest day of the year. Maximum emissions are calculated assuming a single event with the highest fastest mile value for the annual period.

The recommended emission factor equation presented above assumes that all of the erosion potential corresponding to the fastest mile of wind is lost during the period between disturbances. Because the fastest mile event typically lasts only about 2 min, which corresponds roughly to the halflife for the decay of actual erosion potential, it could be argued that the emission factor overestimates particulate emissions. However, there are other aspects of the wind erosion process which offset this apparent conservatism:

1. The fastest mile event contains peak winds which substantially exceed the mean value for the event.

2. Whenever the fastest mile event occurs, there are usually a number of periods of slightly lower mean wind speed which contain peak gusts of the same order as the fastest mile wind speed.

Of greater concern is the likelihood of overprediction of wind erosion emissions in the case of surfaces disturbed infrequently in comparison to the rate of crust formation.

11.2.7.4 Example calculation for wind erosion emissions from conically shaped coal pile

A coal burning facility maintains a conically shaped surge pile 11 m in height and 29.2 m in base diameter, containing about 2000 Mg of coal, with a bulk density of 800 kg/m^3 (50 lb/ft^3). The total exposed surface area of the pile is calculated as follows:

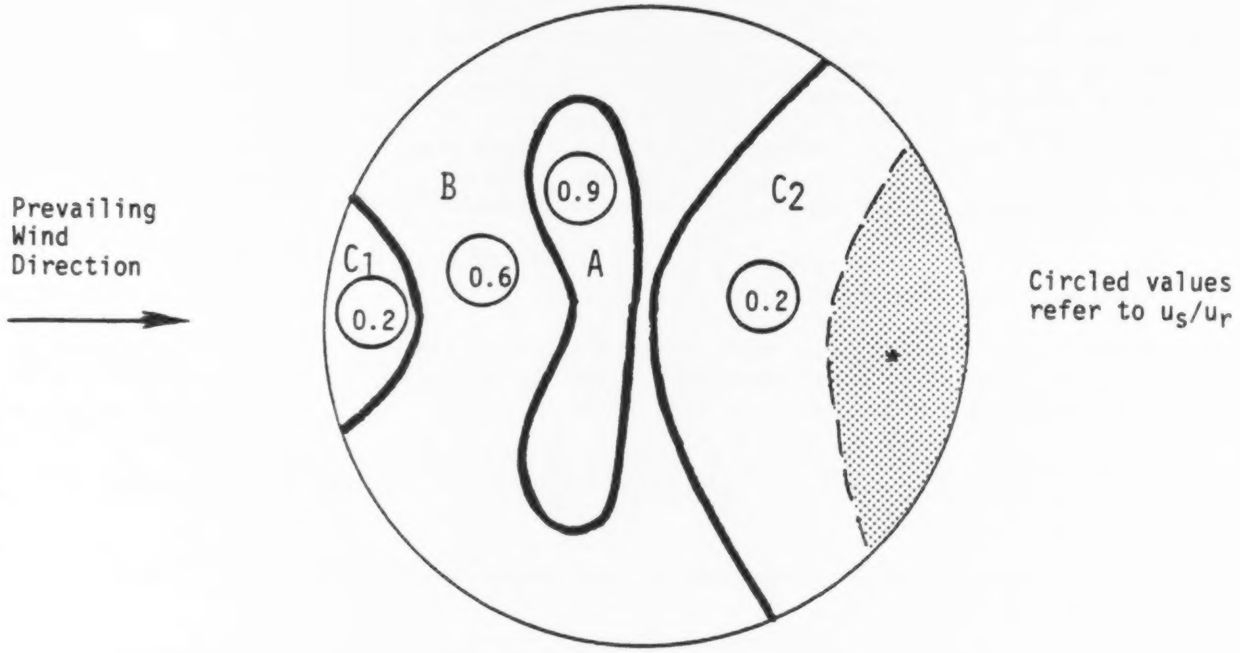
$$S = \quad r \quad r^2 + h^2$$

$$= 3.14(14.6) \quad (14.6)^2 + (11.0)^2$$

$$= 838 \ m^2$$

Coal is added to the pile by means of a fixed stacker and reclaimed by front-end loaders operating at the base of the pile on the downwind side. In addition, every 3 days 250 Mg (12.5% of the stored capacity of coal) is added back to the pile by a topping off operation, thereby restoring the full capacity of the pile. It is assumed that (a) the reclaiming operation disturbs only a limited portion of the surface area where the daily activity is occurring, such that the remainder of the pile surface remains intact, and (b) the topping off operation creates a fresh surface on the entire pile while restoring its original shape in the area depleted by daily reclaiming activity.

Because of the high frequency of disturbance of the pile, a large number of calculations must be made to determine each contribution to the total annual wind erosion emissions. This illustration will use a single month as an example.


Prevailing
Wind
Direction
B
0.9
C_2
C_1
0.6
A
0.2
0.2
*
Circled values refer to u_s/u_r

* A portion of C_2 is disturbed daily by reclaiming activities.

Area ID	$\frac{u_s}{u_r}$	Pile Surface %	Pile Surface Area (m^2)
A	0.9	12	101
B	0.6	48	402
C_1 + C_2	0.2	40	335
			838

Figure 11.2.7-3. Example 1: Pile surface areas within each wind speed regime.

Step 1: In the absence of field data for estimating the threshold friction velocity, a value of 1.12 m/s is obtained from Table 11.2.7-2.

Step 2: Except for a small area near the base of the pile (see Figure 11.2.7-3), the entire pile surface is disturbed every 3 days, corresponding to a value of N = 120/yr. It will be shown that the contribution of the area where daily activity occurs is negligible so that it does not need to be treated separately in the calculations.

Step 3: The calculation procedure involves determination of the fastest mile for each period of disturbance. Figure 11.2.7-4 shows a representative set of values (for a 1 month period) that are assumed to be applicable to the geographic area of the pile location. The values have been separated into 3 day periods, and the highest value in each period is indicated. In this example, the anemometer height is 7 m, so that a height correction to 10 m is needed for the fastest mile values. From Equation 5,

$$u^{+}_{10} = u^{+}_{7} \frac{\ln (10/0.005)}{\ln (7.0.005)}$$

$$u^{+}_{10} = 1.05 \, u^{+}_{7}$$

Step 4: The next step is to convert the fastest mile value for each 3 day period into the equivalent friction velocities for each surface wind regime (i. e., u_s/u_r ratio) of the pile, using Equations 6 and 7. Figure 11.2.7-3 shows the surface wind speed pattern (expressed as a fraction of the approach wind speed at a height of 10 m). The surface areas lying within each wind speed regime are tabulated below the figure.

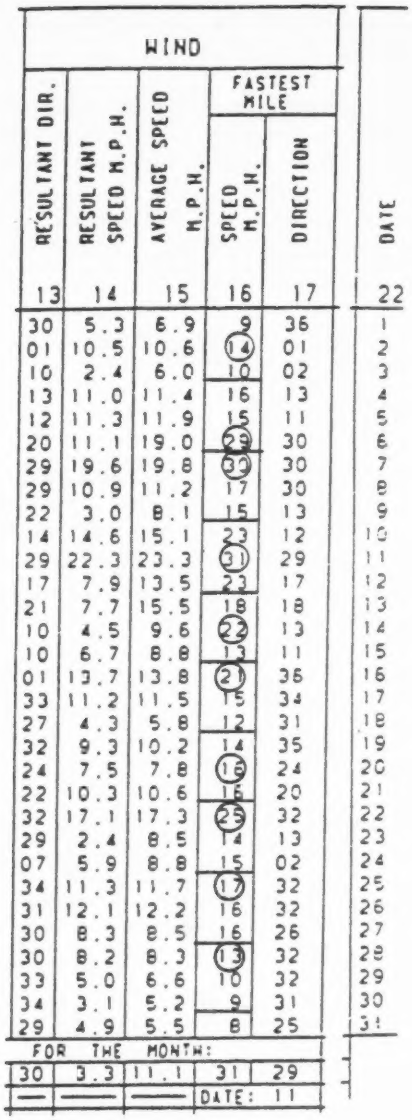
The calculated friction velocities are presented in Table 11.2.7-4. As indicated, only three of the periods contain a friction velocity which exceeds the threshold value of 1.12 m/s for an uncrusted coal pile. These three values all occur within the $u_s/u_r = 0.9$ regime of the pile surface.

Step 5: This step is not necessary because there is only one frequency of disturbance used in the calculations. It is clear that the small area of daily disturbance (which lies entirely within the $u_s/u_r = 0.2$ regime) is never subject to wind speeds exceeding the threshold value.

Local Climatological Data

DEPARTMENT OF COMMERCE • UNITED STATES OF AMERICA

MONTHLY SUMMARY



WIND					
RESULTANT DIR. 13	RESULTANT SPEED M.P.H. 14	AVERAGE SPEED M.P.H. 15	FASTEST MILE SPEED M.P.H. 16	FASTEST MILE DIRECTION 17	DATE 22
30	5.3	6.9	9	36	1
01	10.5	10.6	14	01	2
10	2.4	6.0	10	02	3
13	11.0	11.4	16	13	4
12	11.3	11.9	15	11	5
20	11.1	19.0	29	30	6
29	19.6	19.8	30	30	7
29	10.9	11.2	17	30	8
22	3.0	8.1	15	13	9
14	14.6	15.1	23	12	10
29	22.3	23.3	31	29	11
17	7.9	13.5	23	17	12
21	7.7	15.5	18	18	13
10	4.5	9.6	22	13	14
10	6.7	8.8	13	11	15
01	13.7	13.8	21	36	16
33	11.2	11.5	15	34	17
27	4.3	5.8	12	31	18
32	9.3	10.2	14	35	19
24	7.5	7.8	16	24	20
22	10.3	10.6	16	20	21
32	17.1	17.3	25	32	22
29	2.4	8.5	14	13	23
07	5.9	8.8	15	02	24
34	11.3	11.7	17	32	25
31	12.1	12.2	16	32	26
30	8.3	8.5	16	26	27
30	8.2	8.3	13	32	28
33	5.0	6.6	10	32	29
34	3.1	5.2	9	31	30
29	4.9	5.5	8	25	31
FOR THE MONTH:					
30	3.3	11.1	31	29	
—	—	—	DATE:	11	

Figure 11.2.7-4. Daily fastest miles of wind for periods of interest.

TABLE 11.2.7-4. EXAMPLE 1: CALCULATION OF FRICTION VELOCITIES

3 Day period	u^+_7 (mph)	u^+_7 (m/s)	u^+_{10} (mph)	u^+_{10} (m/s)	u_s/u_r	$u^* = 0.1\ u^+_s$ (m/s) 0.2	0.6	0.9
1	14	6.3	15	6.6		0.13	0.40	0.59
2	29	13.0	31	13.7		0.27	0.82	1.23
3	30	13.4	32	14.1		0.28	0.84	1.27
4	31	13.9	33	14.6		0.29	0.88	1.31
5	22	9.8	23	10.3		0.21	0.62	0.93
6	21	9.4	22	9.9		0.20	0.59	0.89
7	16	7.2	17	7.6		0.15	0.46	0.68
8	25	11.2	26	11.8		0.24	0.71	1.06
9	17	7.6	18	8.0		0.16	0.48	0.72
10	13	5.8	14	6.1		0.12	0.37	0.55

Steps 6 and 7: The final set of calculations (shown in Table 11.2.7-5) involves the tabulation and summation of emissions for each disturbance period and for the affected subarea. The erosion potential (P) is calculated from Equation 3.

TABLE 11.2.7-5. EXAMPLE 1: CALCULATION OF PM_{10} EMISSIONS[a]

3 Day period	u^* (m/s)	$u^* - u^{*t}$ (m/s)	P (g/m^2)	ID	Pile Surface Area (m^2)	kPA (g)
2	1.23	0.11	3.45	A	101	170
3	1.27	0.15	5.06	A	101	260
4	1.31	0.19	6.84	A	101	350
					Total PM_{10} emissions =	780

[a] where $u^*_t = 1.12$ m/s for uncrusted coal and $k = 0.5$ for PM_{10}.

For example, the calculation for the second 3 day period is:

$$P_2 = 58(1.23 - 1.12)_2 + 25(1.23 - 1.12)$$

$$= 0.70 + 2.75 = 3.45\ g/m^2$$

The PM_{10} emissions generated by each event are found as the product of the PM_{10} multiplier ($k = 0.5$), the erosion potential (P), and the affected area of the pile (A).

As shown in Table 11.2.7-5, the results of these calculations indicate a monthly PM_{10} emission total of 780 g.

11.2.7.5 Example calculation for wind erosion from flat area covered with coal dust

A flat circular area of 29.2 m in diameter is covered with coal dust left over from the total reclaiming of a conical coal pile described in the example above. The total exposed surface area is calculated as follows:

$$S = \frac{\ }{4} d^2 = 0.785\ (29.2)^2 = 670\ m^2$$

This area will remain exposed for a period of 1 month when a new pile will be formed.

Step 1: In the absence of field data for estimating the threshold friction velocity, a value of 0.54 m/s is obtained from Table 11.2.7-2.

Step 2: The entire surface area is exposed for a period of 1 month after removal of a pile and N = 1/yr.

Step 3: From Figure 11.2.7-5, the highest value of fastest mile for the 30 day period (31 mph) occurs on the 11th day of the period. In this example, the reference anemometer height is 7 m, so that a height correction is needed for the fastest mile value. From Step 3 of the previous example, $u^+_{10} = 1.05\ u^+_7$, so that $u^+_{10} = 33$ mph.

Step 4: Equation 4 is used to convert the fastest mile value of 33 mph (14.6 m/s) to an equivalent friction velocity of 0.77 m/s. This value exceeds the threshold friction velocity from Step 1 so that erosion does occur.

Step 5: This step is not necessary because there is only one frequency of disturbance for the entire source area.

Steps 6 and 7: The PM_{10} emissions generated by the erosion event are calculated as the product of the PM_{10} multiplier (k = 0.5), the erosion potential (P) and the source area (A). The erosion potential is calculated from Equation 3 as follows:

$$\begin{aligned} P &= 58(0.77 - 0.54)2 + 25(0.77 - 0.54) \\ &= 3.07 + 5.75 \\ &= 8.82\ g/m^2 \end{aligned}$$

Thus the PM_{10} emissions for the 1 month period are found to be:

$$\begin{aligned} E &= (0.5)(8.82\ g/m^2)(670\ m^2) \\ &= 3.0\ kg \end{aligned}$$

References for Section 11.2.7

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APPENDIX C.3

SILT ANALYSIS PROCEDURES

1. Select the appropriate 8 inch diameter 2 inch deep sieve sizes. Recommended standard series sizes are 3/8 inch No. 4, No. 20, No. 40, No. 100, No. 140, No. 200, and a pan. The No. 20 and the No. 200 are mandatory. Comparable Tyler Series sizes can also be used.

2. Obtain a mechanical sieving device such as a vibratory shaker or a Roto-Tap (without the tapping function).

3. Clean the sieves with compressed air and/or a soft brush. Material lodged in the sieve openings or adhering to the sides of the sieve should be removed without handling the screen roughly, if possible.

4. Obtain a scale with capacity of at least 1600 grams, and record its make, capacity, smallest increment, date of last calibration, and accuracy.

5. Record the tare weight of sieves and pan, and check the zero before every weighing.

6. After nesting the sieves in decreasing order of hole size, and with the pan at the bottom, dump dried laboratory sample into the top sieve, preferably immediately after moisture analysis. The sample should weigh between 800 and 1600 grams (1.8 and 3.5 pounds). Brush fine material adhering to the sides of the container into the top sieve, and cover the top sieve with a special lid normally purchased with the pan.

7. Place nested sieves into the mechanical device, and sieve for 10 minutes. Remove pan containing minus No. 200 and weigh its contents. Repeat the sieving in 10 minute intervals until the difference between two successive pan sample weights is less than 3.0 percent when the tare of the pan has been substracted. Do not sieve longer than 40 minutes.

8. Weigh each sieve and its contents, and record the weight. Remember to check the zero before every weighing.

9. Collect the laboratory sample, and place it in a separate container if further analysis is expected.

10. Calculate the percent of mass less than the 200 mesh screen (75 micrometers). This is the silt content.

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